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Conventional Combining Scheme in Cooperative Spectrum Sensing

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Abstract: ***Spectrum Sensing (SS) is a key constituent of software defined radio (SDR) or Cognitive radio (CR). Spectrum sensing (SS) investigate the white hole in allotted spectrum to the primary user. Cooperative spectrum sensing (CSS) has work in a best manner than any other spectrum sensing (SS) technique to detect white space or spectrum hole in the licensed spectrum. In this paper we compare various combining scheme that are to be perform at the Fusion centre (FC). Fusion centre (FC) is the central part of Cooperative spectrum sensing (CSS) that combines individual node decision. Simulation has performed for hard and soft combining scheme. According to the simulation the soft combining scheme performed better then hard combining scheme but the complexity and bandwidth (BW) requirement in the soft combining is more than hard combining scheme. In the proposed paper we also explore detection error that is to be present in various combining scheme.***

Keywords: ***Spectrum sensing (SS), software defined radio (SDR), Fusion centre (FC), hard combining, soft combining.***

I. INTRODUCTION

Wireless application is increasing day by day therefore effective utilization of frequency band is very necessary but in Static allocation of frequency band some of the frequency band remains underutilize therefore dynamic allocation of frequency band is need of hour. Cognitive radio (CR) is the solution of above problem it uses dynamic allocation of the frequency band. Spectrum sensing(SS) is the central part of cognitive radio (CR) it monitor the presence of primary user (PU) in the accessible spectrum if primary user(PU) is found to be absent then cognitive radio will hand over the spectrum to the secondary user (SU) without destructive intervention with primary user (PU).The concept of signal detection was first given by [1].In the above proposal the energy of received signal is being measured in time window to judge whether the primary user(PU) is present or not . There are various spectrum sensing (SS) technique have been developed like energy detection (ED), match filter (MF) cyclostationary or feature detection [2].

Energy detector(ED) is a blind, non-coherent spectrum sensing technique it does not require prior knowledge of input signal.

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In the energy detection spectrum sensing (SS) energy of received signal is being measured for a time interval then it is compare with predefined threshold to decide whether the primary user are present or not energy detector (ED) have low implementation cost and have better detection probability (p_d) but at low signal to noise ratio (SNR) Energy detector(ED) cannot differentiate between primary user signal (PUS) and that of noise [3]. Match filter (MF) detection scheme is coherent detection scheme of the spectrum sensing (SS) where prior knowledge of the input signal is very necessary. In match filter detection convolution is being performed between unknown primary signal and that of time shifted version of the transfer function of match filter and output is being compare with the predefined threshold the match filter (MF) detection perform better then energy detector at low (SNR) region but the drawback of this technique is it has high realization complexity [4]. Cyclostationary or feature detection method feature of received signal is used to differentiate between the signal and noise it is also coherent detection technique but has high complexity in Computation. Prior information of the input signal is necessary [5] in the feature detection method.

Cooperative spectrum sensing (CSS) is a receiver detection based spectrum sensing technique that is performed when various Cognitive radio users (CRU) perform Spectrum sensing .Each individual Cognitive radio user give the sensing information to the central server that is also known as the fusion center (FC) central sever then aggregate all the individual cognitive radio (CR) and give the final decision whether the spectrum is vacant or not [6]. Three topology are being used in the cooperative spectrum sensing (CSS) that are Centralize coordinated topology in which there all node give their decision to central hub that give final decision whether the white space is present or not next is decentralize coordinated system in which there is no central hub each node communicate their decision to each other by some gossip or clustering algorithm third one is decentralize uncoordinated topology in which neither there will be a server to aggregate all the information nor each node share their information to each other [6] . At the Fusion center (FC) individual Cognitive radio (CR) can combined be combined by the soft combining or hard Combining scheme .In proposed work there is a relative comparison is being performed on the soft combining and hard combining scheme. Spectrum sensing (SS) is typical due to the time variation feature of the channel and shadowing effect that can be overcome in the cooperative spectrum sensing (CSS) . As we know that spatial diversity of various CR user is present in (CSS).

In section 2 individual node modeling and system model is designed .In section 3 various combining rules are explored in section 4numerical result have discussed and in section 5 conclusion from complete article have represented.

II. SYSTEM MODELING

A. Node Modeling

In the Cooperative spectrum sensing (CSS) the Energy Detector(ED) will work as the individual node due to the low implementation complexity.

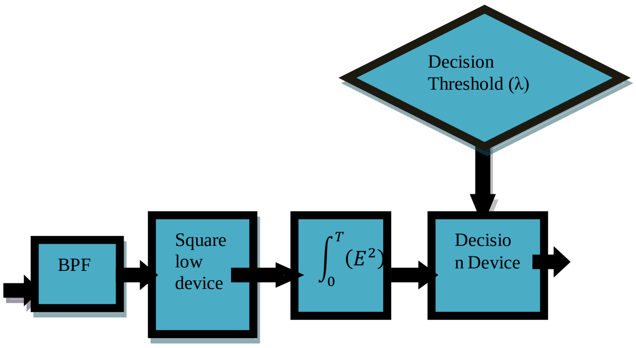

Fig. 1. Energy Detector(ED)

In the Energy Detector (ED) the signal is received at the receiving end then it is filter by a Band Pass Filter (BPF) with the desired Band Width (BW) to select the signal of interest and to reject all other close by signal and noise .Output of the Band Pass Filter (BPF) given to a square- law nonlinear device. To measure the energy of the received signal output of non linear device is integrated over the time period T. Now the energy of received signal is then examine by a test statics in which the received signal energy for some sensing interval is compared with the predefined threshold- λ. Test statics can give two hypothesis in their result by equation(1) . First hypothesis H0 indicate the primary user (PU) is not present only noise is present hypothesis H1 indicate primary user (PU) as well as noise both are present

$$y(t) = \begin{cases} \mathrm{n(t)} & \mathrm{Hypothesis H_0} \\ \alpha\mathrm{s(t)} + \mathrm{n(t)} & \mathrm{Hypothesis\ H_1} \end{cases} \tag{1}$$

$s(t)$ is the unknown deterministic signal element $n(t)$ is the Additive White Gaussian noise(AWGN). Noise considered in this model is Additive White Gaussian (AWGN) having zero mean and variance σ^2. α is the gain of channel that is assumed to be constant throughout the sensing time interval. The received signal at energy detector is $y(t)$. The time bandwidth product $u = TW$ so in the test static hypothesis H0 will follow central Chi Square Distribution and hypothesis H1 will follow Non central Chi Square Distribution with 2u Degree of liberty so that probability density function (PDF)define in [7] by equation (2)

$$F_y(\mathrm{y}) = \begin{cases} \frac{1}{2^{\mathrm{u}}\Gamma(\mathrm{u})} \mathrm{y}^{\mathrm{u}-1} \mathrm{e}^{-\mathrm{y}/2} & \mathrm{H_0} \\ \frac{1}{2}\left(\frac{\mathrm{y}}{2\gamma}\right)^{\frac{\mathrm{u}-1}{2}} \mathrm{e}^{-\frac{\mathrm{y}+2\gamma}{2}} \mathrm{I}_{\mathrm{u}-1}\left(\sqrt{2\mathrm{y}\gamma}\right) & \mathrm{H_1} \end{cases} \tag{2}$$

γ Denotes signal to noise ratio (SNR), Gama function is $\Gamma(a) = \int_0^\infty t^{(a-1)} e^{-t} dt$ and modified Bessel function of first kind$I_n(x) = (1/\pi) \int_0^\pi \cos(n\theta) e^{x\cos\theta}\, d\theta$.

Investigation of the Spectrum sensing (SS) is done by region of convergence (ROC) curve. ROC curve is the curve among Detection probability(P_d) and False alarm probability (P_f).Detection probability(P_d) is the probability of decision device to detect primary user (PU) when in fact primary user (PU) is present or it is a probability of correct detection. Probability of false alarm (P_f) describe the probability that primary user signal (PUS) is present but in fact there was only noise is present. Opposite of detection probability is missed detection probability(P_{md}). Integrating the equation for limit zero o infinity we will find the expression (3),(4) of P_f and P_d as

$$P_f = \frac{\Gamma(\mathrm{u}, \frac{\lambda}{2})}{\Gamma(\mathrm{u})} \tag{3}$$

$$P_d = Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \tag{4}$$

Where$\Gamma(a, x) = \int_x^\infty t^{(a-t)} e^{-t} dt$ and

$$Q_m(a, b) = \left(\frac{1}{a^{(m-1)}}\right) \int_b^\infty x^m\, e^{-(x^2+a^2)/2} I_{(m-1)}(ax) dx$$

Represents in-complete Gama function, Marcum Q-function [8]. Predefined threshold (λ) is very important in the design of Energy detector because it effect all three type of probability detection probability (p_d), probability of false alarm (p_f), missed detection probability(p_{md}).From the equation (1) fix the value of P_f to find out the detection threshold (λ) use this detection threshold (λ) to find out the detection probabilityP_d for the various different signal to noise ratio(γ).

B. System Modeling

Cooperative spectrum sensing model consist various individual node in the proposed model Energy detector (ED) will be considered as the individual node and the proposed model is being designed for centralize coordinated topology.

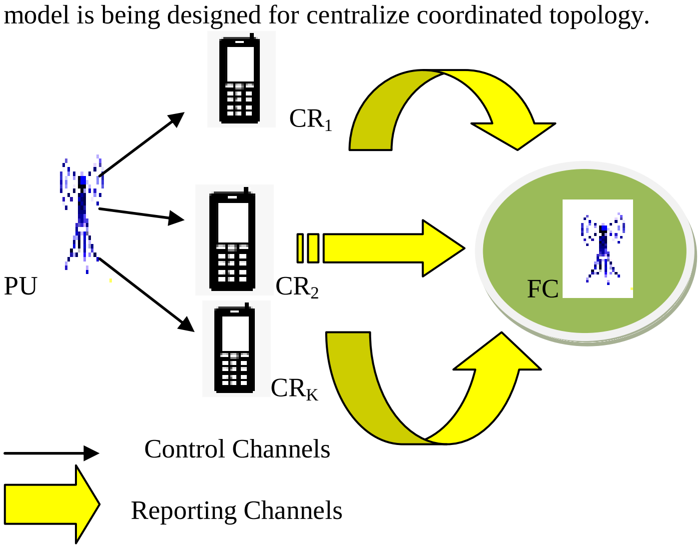

Fig. 2. Centralize Cooperative Spectrum Sensing System simplest model

Consider there are K no of secondary user (SU) that are Indexed (j=1, 2, 3…K) these all secondary user (SU) perform the spectrum sensing (SS) individually on N number of sample.

For random j^{th} secondary user (SU) spectrum sensing (SS) task is performed with the hypothesis H0 and H1 as in node modeling is explained

$$y_j(t) = \begin{cases} n_j(t) & : H_0 \\ \alpha_j s(t) + n_j(t) & : H_1 \end{cases} \quad (5)$$

Where $y_j(t)$ is the received signal by the j^{th} secondary user (SU), α_j is gain of jth channel between primary user and j^{th} secondary user $n_j(t)$ is the White Gaussian Noise (AWGN) with zero mean single side band power spectral density(PSD) of the noise is N0 . The energy and power of each j^{th} energy detector(ED) node can be calculated in [9] by the expression (6), (7).

$$U_j = \sum_1^N x_i^2(n) \quad (6)$$

$$P_j = \sum_1^N x_i^2(n)\ ]/N \quad (7)$$

All the j node will calculate the energy now information is being sent to the central server that is also known as Fusion center (FC).Fusion center is the part of the cooperative spectrum sensing (CSS) where all j individual node information is aggregated.

There are two ways by the aggregation of the result can be performed at the fusion center (FC) soft combining scheme and hard combining scheme. In the soft combining the energy calculated by individual node will be forwarded directly to the fusion center (FC).

Fusion center(FC) then combine the energy received from all respective node and compare with the predefined threshold and give the final decision whether the spectrum is vacant or not in the hard combining scheme each individual node take the 1 bit decision whether the spectrum is vacant or not. All 1 bit decision are transferred to Fusion center where all the decision are combined by some logical combining technique.

III. FUSION RULE

Fusion centre or the central hub is responsible to give the final conclusion weather the white space is present or not. There are two type of combining can be perform at fusion centre

A. Soft Combining

In the soft combining each individual node is not capable to take the decision the node will only calculate the energy of the received signal. The energy calculated by each node will be will be summed at the Fusion centre (FC) and compared with the required threshold to take final decision whether the spectrum is vacant or not. For finding out the decision threshold at the fusion center put the value of false alarm probability at fusion center fix then find out the predefined threshold. To remove the interference by primary user (PU) false alarm probability should be kept small. In the soft combining energy of the individual node will be added by linear weighted combining scheme

$$Y_F = \sum_{j=1}^{j=K} W_j U_j = W^T U \quad (8)$$

Where $W = [W_1, W_2, W_3 \dots W_K]^T$ and $U = [U_1, U_2, U_3 \dots U_K]^T$. The submission Y_F is a Gaussian distribution function. For the narrowband signal the calculation of the signal means and variance are given in [10] by the equation (9) to (12)

$$M[Y_F/H_0] = \sum_{j=1}^{M} W_j\, M[U_j/H_0] = S_{H_0}^T W \quad (9)$$

$$M[Y_F/H_1] = \sum_{j=1}^{M} W_j\, M[U_j/H_1] = S_{H_1}^T W \quad (10)$$

$$V[Y_F/H_0] = \sum_{j=1}^{M} W_j^2\, V[U_j/H_0] = W^T L_{H_0} \quad (11)$$

$$V[Y_F/H_1] = \sum_{j=1}^{M} W_j^2\, V[U_j/H_1] = W^T L_{H_1} W \quad (12)$$

Where $S_{H_0}^T = [\sigma_1^2, \sigma_2^2, \sigma_3^2 \dots . \sigma_k^2]^T$

$S_{H_1}^T = [\sigma_1^2(1+\gamma_1), \sigma_2^2(1+\gamma_2), \dots . . \sigma_K^2(1+\gamma_K)]^T$

$L_{H_0} = 2DIAG(S_{H_0})/N$

$L_{H_1} = 2DIAG[\sigma_1^4(1+2\gamma_1), \sigma_2^4(1+2\gamma_2) \dots \sigma_K^4(1+2\gamma_K)]$

σ_j is the standard deviation(SD) of the N noise sample and γ_j is the observed signal to noise ratio of j^{th} node. False alarm probability (P_F^{FUS}) and the detection probability(P_D^{FUS}) at the Fusion centre (FC) is represented by the following equation(13),(14).

$$P_F^{FUS} = Q(\{\lambda_{FUS} - M\{Y_F/H_0\}/\sqrt{V\{Y_F/H_0\}}) \quad (13)$$

$$P_D^{FUS} = Q(\{\lambda_{FUS} - M\{Y_F/H_0\}/\sqrt{V\{Y_F/H_1\}}) \quad (14)$$

From equation (13) find out the detection threshold at the fusion centre put it in the equation (14) to find out Probability of detection at the fusion centre.

1. Equal weighted combining (EWC)

In the equal weighted combining the square of the energy calculated by each node will be directly forwarded to the Fusion centre (FC) keeping the weights of all individual link weight equal to unity

$$W = [1,1,1 \dots 1]^T$$

$$U = [U_1, U_2, U_3 \dots U_K]^T$$

$$U_{EWC} = \sum_{j=1}^{K} U_j \quad (15)$$

U_j is the statistics of the j^{th} node the probability of detection and probability of false alarm at the fusion centre are determined in [11] and represented by the equation (16),(17).

$$Q_D^{EWC} = Q_{mj}\,(\sqrt{2\gamma_{EWC}}, \sqrt{\lambda}) \quad (16)$$

$$Q_D^{EWC} = \Gamma(mj, \lambda/2)/\Gamma(mj) \quad (17)$$

$\gamma_{EWC} = \sum_{j=1}^{K} \gamma_j$. γ_j is the received SNR at the j^{th} node .

2. Maximum weighted combining (MWC)

The measured energy at every node is multiplied by the normalize weight the weight value at every node will be depend upon the received SNR of the various cognitive radio user (CRU). Detection and false alarm probability is given by expression (18),(19) and developed in [12].

$$U_{MWC} = \sum_{j=1}^{K} W_j U_j$$

$$Q_D^{MWC} = Q_{mj}\,(\sqrt{2\gamma_{MWC}}, \sqrt{\lambda}) \quad (18)$$

$$Q_D^{MWC} = \Gamma(m, \lambda/2)/\Gamma(m) \quad (19)$$

$\gamma_{MWC} = \sum_{j=1}^{K} \gamma_j$. γ_j is the average signal to noise ratio (SNR) at the j^{th} node .

B. Hard combining scheme

In hard combining scheme each individual node is capable to take decision whether the spectrum is vacant or not by comparing the signal energy to the predetermined threshold. Every individual 1 bit decision to the Fusion centre(FC) if the measured energy is greater than predefined threshold for jth (CR) user then node give 1 to the fusion centre Otherwise it give 0 bit to the fusion centre. The main advantage of the scheme is it require less bandwidth then soft combining scheme for one bit decision 1 indicate the primary user(PU) is present there for zero bit decision primary user is not present there. Aggregation of the all decision at fusion centre is being performed by the three logical combining AND combining, OR combining, Majority combining [13],[14]. If K are total no CR user and n is the no of user that give hypothesis H1. Then detection performance is given by the following expression (20), (21) explored in [13]

$$Q_d^{COOP} = \sum_{l=n}^{K} \binom{K}{l} P_{dj}^{l} \left(1 - P_{dj}^{K-l}\right) \quad (20)$$

$$Q_f^{COOP} = \sum_{l=n}^{K} \binom{K}{l} P_{fj}^{l} \left(1 - P_{fj}^{K-l}\right) \quad (21)$$

1. AND combining scheme

At the fusion centre the combining will be perform using logical AND operation. If all the secondary user (SU) node give the logical 1 under the hypothesis H1 then the decision gave by the fusion centre will be1 [15]. Region of convergence curve for this rule can be find out l=k in the equation (20) and (21) and develop the expression of detection probability and false alarm probability represented by equation (22),(23)

$$Q_{d,AND}^{COOP} = P_{dj}^{K} \quad (22)$$

$$Q_{f,AND}^{COOP} = P_{fj}^{K} \quad (23)$$

2. OR combining scheme

In the OR fusion rule final decision will be taken according to the logical OR operation at the fusion centre. If any one of the CR user give logical 1 decision under the hypothesis H1 the fusion centre (FC) give logical1decision [16]. In the equation (20) and (21), if we set K =1 then we will find expression for the detection probability and the false alarm probability at the fusion centre (FC) represented by (24), (25)

$$Q_{d,OR}^{COOP} = 1 - \left(1 - P_{dj}^{K}\right) \quad (24)$$

$$Q_{f,OR}^{COOP} = 1 - \left(1 - P_{fj}^{K}\right) \quad (25)$$

3. Majority combining scheme

In the majority combining scheme all secondary user (SU) node give the decision to the fusion centre if at least half of the node give the logical 1 to the fusion centre then the final decision given by the fusion centre (FC) will be 1 Under the hypothesis H1[14]. The mathematical function for the detection probability and false alarm probability is obtained by putting l=n/2 in expression (20) and (21) and generate quality of measure detection probability and false alarm probability represented by equation (26), (27)

$$Q_{d\,MAJ}^{COOP} = \sum_{l=n/2}^{K} \binom{K}{l} P_{dj}^{l} \left(1 - P_{dj}^{K-l}\right) \quad (26)$$

$$Q_{f\,MAJ}^{COOP} = \sum_{l=n/2}^{K} \binom{K}{l} P_{fj}^{l} \left(1 - P_{fj}^{K-l}\right) \quad (27)$$

IV. SIMULATION AND RESULT ANALYSIS

The simulation test is being performed on Matlab2017a. For the result analysis N= 1000 sample under BPSK modulation is being generated. For the experiment number of CR user are being taken K=8 and the channel model is AWGN channel. The signal have mean signal to noise ratio -20 db. The region of convergence curve (ROC) is being generated for the various combining scheme. Figure 3 consist ROC curve between Detection probability (Qd) vs false alarm probability (Qf) . Figure 4 consist ROC curve between missed detection probability (Qmd) vs probability of false alarm Qf). Figure 5 consist detection error probability (Qe) vs false alarm probability(Qf). In the above simulation no channel fading effect is being considered. To protect interference from the primary both at individual node and at the fusion center the false alarm probability should be kept small higher the value of false alarm probability reflect inefficient utilization & high interference at the individual node or at the fusion center(FC).

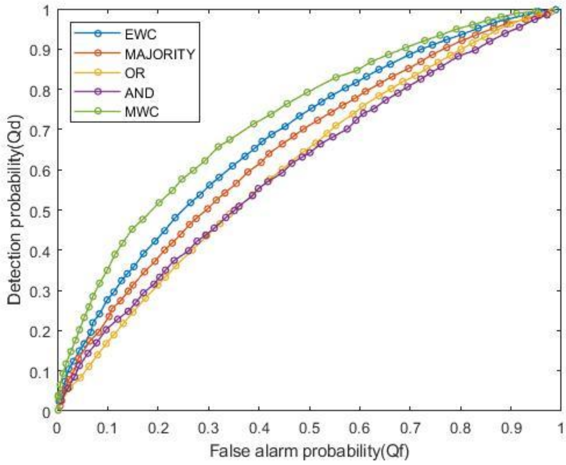

Fig. 3. Detection Probability(Q_d) and False Alarm Probability (Q_f)

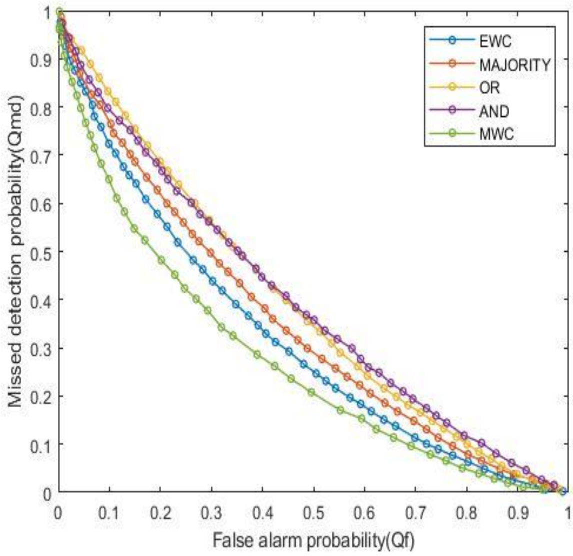

Fig. 4. Missed Detection Probability(Q_{md}) and False Alarm Probability (Q_f)

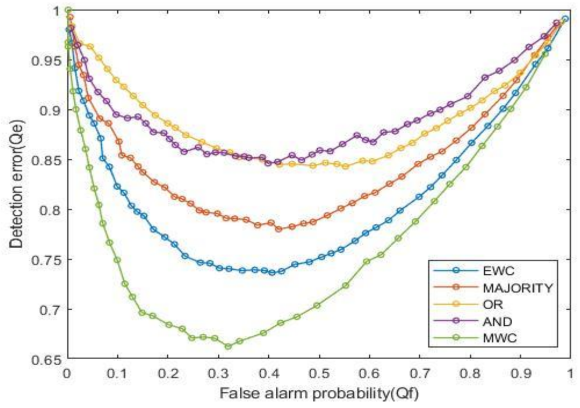

Fig. 5. Detection Error Probability(Qe) and False Alarm Probability (Q_f)

According to the slandered IEEE802.22 false alarm probability at fusion center of at the (ED) node should be .1. If the value of false alarm probability is greater then .5 then a high level interference can be perform at individual node or at the fusion center. According to the simulation result of figure 3 and f it is being observed that at low value of (Qf) the performance of AND combining rule is better than OR combining result but after a higher value (Qf) the result of OR better then AND. Majority rule is closed proximity to the hard combining scheme out of three soft combining scheme majority rule perform better than any other type of the soft combining scheme in the hard combining scheme Maximum weighted combining(MWE) will perform better then Equal weighted combining scheme.ROC curve 4 explains the variation of interference with respect to false alarm probability .Interface at the fusion center will be proportional to the (Qmd) .Maximum weighted combining scheme have less interference at the fusion center than any other combining technique . Detection error probability (Qe) is the error perform at the fusion centre in the various combining scheme can be calculated as (Qe) = (Qmd) +(Qf) from the figure 5 we found that the detection error probability is minimum in the maximum weighted combining scheme. From the ROC curve 3 it is clear that the combining scheme that have high detection probability have least detection error probability as then detection probability is increases the detection error is decreases. For the combining rule that have high detection probability under that rule fusion centre have high probability to find primary user (PU) and less interference. Cooperative spectrum sensing (CSS) perform best among all type of spectrum sensing (SS) technique even at low (SNR) region and also have less effect of shadowing & fading. Detection probability (Qd) is increases if the no of secondary user (SU) increases but energy consumption is also increases so we have taken a tradeoff between no of user and that of energy consumption.

V. CONCLUSION

Simulation results shows that soft combining scheme perform better then hard combining scheme but the complexity and bandwidth (BW) requirement for soft combining scheme is greater than the hard combining scheme also in the soft combining scheme the maximum weighted combining (MWC) will perform better then that equal weighted combining (EWC).Among the hard combining scheme MAJORITY combining is better than is better than OR combining & AND combining. Out of these all rule Maximum weighted combining (MWC) is best

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Dr. N. S. Beniwal received his B.E. degree from Engineering College Kota, (Raj.), India in 1999, M.E. degree from M.R.E.C., Jaipur (Raj.), India and Ph.D. from IIT Roorkee (U.K.), India. Currently, he is Associate Professor in BIET, Jhansi (U.P.), India. He has published to his credit more than 50 research papers in different National and International Journals. His current areas of research interest are solar energy, failure analysis of systems, optimization, cognitive radio, etc. Dr. Beniwal have guided 5 PhD scholars and more than 20 M. Tech research scholar.

Prof. Shivendra Nath Sharan has completed his PhD from IIT –Delhi in the year 1988. Dr. Sharan has more than 30 years experience in teaching and research. Dr. Sharan had experience of various academic position currently he is the area director at NIIT University Nimrana. Dr. Sharan has more than 40 research paper in national & international journal. Dr sharan have supervised more than 10 research scholar .Dr Sharan is the Member of Expert Advisory committee, CSTT, MHRD, New Delhi for Nanotechnologies Glossary held in August 2018. Dr. Sharan is External member of Academic Council ICFAI University Jaipur. His Research area communication system, Signal processing.