International Journal of Electrical and Electronic Engineering & Telecommunications

*ISSN 2319 – 2518 www.ijeetc.com*
*Vol. 6, No. 2, April 2017*


*Research Paper*

# A SURVEY OF COOPERATIVE SPECTRUM SENSING APPROACHES AND DATA FUSION SCHEMES IN COGNITIVE RADIO NETWORKS

**D B V Ravisankar[1]* and N Venkateswararao[2]**

*Corresponding Author: **D B V Ravisankar***

Spectrum Sensing is the most crucial task in Cognitive Radio Networks (CRN). The role of Secondary User (SU) is to sense the spectrum continuously and detect whether the Primary User (PU) signal is present or absent. The detection performance in practice is often compromised with multipath fading, shadowing and receiver uncertainty issues. To address these issues Cooperative Spectrum Sensing (CSS) is used. Cooperation among multiple secondary users can be utilized to improve the sensing performance and increase the efficiency to detect spectrum holes in CRN. In this paper we present the classification of Cooperative sensing approaches and fusion schemes used in CRN. A comparison of those approaches and schemes is also presented in this paper.

***Keywords:*** Cognitive radio networks, Spectrum sensing, Secondary user, Detection performance.

## INTRODUCTION

In the recent years due the rapid growth of wireless services the demand for available spectrum is increasing multifold. It is observed that it is not the problem of spectrum scarcity but the effective utilization of licensed spectrum is a serious issue which is to be addressed. Cognitive Radio (CR) is a novel approach to address the issue of efficient spectrum utilization. The fundamental task of each CR user in a CRN is to detect the licensed users, also known as primary users (PUs), if they are present and identify the available spectrum if they are absent. This is usually achieved by sensing the RF environment, a process called spectrum sensing. The two main objectives of spectrum sensing are first, CR users should not cause harmful interference to PUs by either switching to an available band or limiting its interference with PUs at an acceptable level and, second, CR users should efficiently identify and exploit

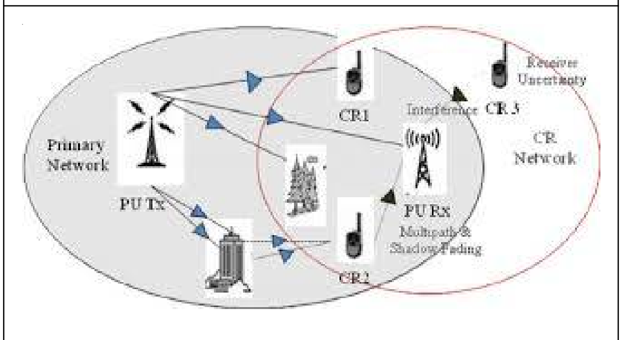
[1] Associate Professor, IT Department, MVSR Engineering College, Nadergul, Hyderabad.

[2] Professor, ECE Department, Bapatla Engineering College, Bapatla.

the spectrum holes for required throughput and quality-of-service (QoS). Thus, the detection performance in spectrum sensing is crucial to the performance of CRN.

The detection performance is based on two metrics: *probability of false alarm* $P_f$, which denotes the probability of a CR user declaring that a PU is present when the spectrum is actually free, and *probability of detection* $P_d$, which denotes the probability of a CR user declaring that a PU is present when the spectrum is occupied by the PU. The main idea of cooperation is to improve the detection performance by taking the advantage of the spatial diversity and reduce false alarm to utilize the idle spectrum more efficiently. The factors such as multipath fading, shadowing, and the receiver uncertainty problem may significantly compromise the detection performance in spectrum sensing. In Figure 1, multipath fading, shadowing and receiver uncertainty are illustrated.

**Figure 1: Sensing Problems**



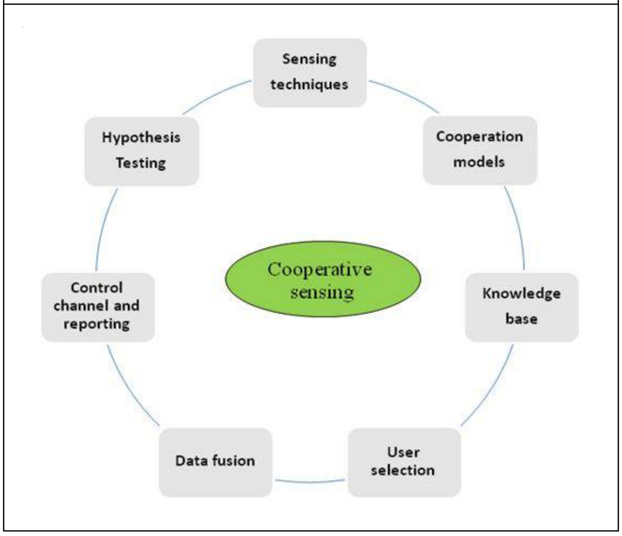

As shown in Figure 1, CR3 suffers from the receiver uncertainty problem because it is located outside the transmission range of primary transmitter. CR2 experiences multipath and shadowing caused by building and trees such that the PU's signal may not be correctly detected. Cooperative spectrum sensing will help to solve these problems if secondary users cooperate by sharing their information.

The three steps in the cooperative sensing process are

1. The fusion center FC selects a channel or a frequency band of interest for sensing and requests all cooperating CR users to individually perform local sensing.
2. All cooperating CR users report their sensing results via the control channel.
3. Then the FC fuses the received local sensing information to decide about the presence or absence of signal and reports back to the CR users.

To implement these steps, seven elements of cooperative sensing are required as shown in Figure 2.

**Figure 2: Elements of Cooperative Spectrum Sensing**




**Cooperation models**: is concerned with how CR users cooperate to perform sensing.

**Sensing techniques**: are used to sense the RF environment, taking observation samples, and employing signal processing techniques for detecting the PU signal or the available spectrum.

**Hypothesis testing**: is a statistical test to determine the presence or absence of a PU. This test can be performed individually by each cooperating user for local decisions or performed by the fusion center for cooperative decision.

**Control channel and reporting**: about how the sensing results obtained by cooperating CR users can be efficiently and reliably reported to the fusion center or shared with other CR users

**Data fusion**: is the process of combining the reported or shared sensing results for making the cooperative decision.

**User selection**: in order to maximize the cooperative gain, this element provides us the way to optimally select the cooperating CR users.

**Knowledge base**: means a prior knowledge included PU and CR user location, PU activity, and models or other information in the aim to facilitate PU detection.

This paper is organized as follows. In Section II a brief description of CR System Model is presented. In Section III the various Cooperative Spectrum Sensing (CSS) approaches are presented followed by data fusion schemes in Section IV. We conclude this paper in Section V.

## SYSTEM MODEL

Consider a cognitive radio network, with $K$ cognitive users (indexed by $k = \{1, 2. . . K\}$) to sense the spectrum in order to detect the existence of the PU. Suppose that each CR performs local spectrum sensing independently by using N samples of the received signal. The spectrum sensing problem can be formulated as a binary hypothesis testing problem with two possible hypothesis $H_0$ and $H_1$.

$$H_o : x_k(n) = w_k(n)$$

$$H_1 : x_k(n) = h_k\, s(n) + w_k(n)$$

where s(n) are samples of the transmitted signal (PU signal), $w_k(n)$ is the receiver noise for the $k^{th}$ CR user which is assumed to be a random process with zero mean and variance $ó_n^2$ and $h_k$ is the complex gain of the channel between the PU and the $k^{th}$ CR user. $H_0$ and $H_1$ represent whether the signal is absent or present respectively.

## COOPERATIVE SPECTRUM SENSING APPROACHES

To facilitate the analysis of cooperative sensing, there are three approaches .This classification of spectrum sensing into three categories is based on how cooperating CR users share the sensing data in the network. They are 1.Centralized 2. Distributed and 3.Relay-assisted.

In Centralized cooperative sensing, a central identity called fusion center (FC) controls the three-step process of cooperative sensing. First, the FC selects a channel or a frequency band of interest for sensing and instructs all cooperating CR users to individually perform local sensing. Second, all cooperating CR users report their sensing results via the control channel. Then the FC combines the received local sensing information, determines the presence of PUs, and diffuses the decision back to cooperating CR users. The classification of CSS is shown in Figure 3.

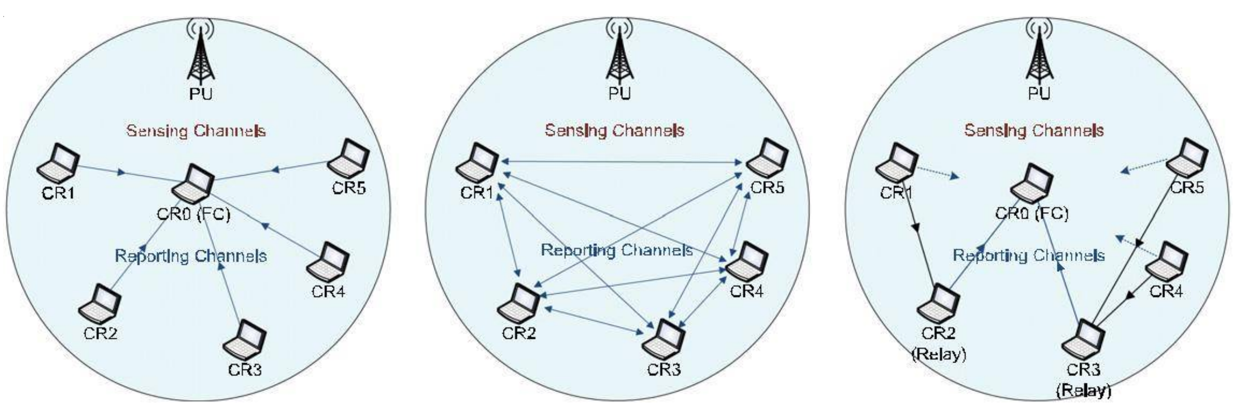
As shown in Figure 3(a), CR0 is the FC and CR1–CR5 are cooperating CR users performing local sensing and reporting the results back to CR0. For local sensing, all CR users are tuned to the selected licensed channel or frequency band where a physical point-to-point link between the PU transmitter and each cooperating CR user for observing the primary signal is called a *sensing channel*. For data reporting, all CR users are tuned to a *control channel* where a physical point-to-point link between each cooperating CR user and the FC for sending the sensing results is called a *reporting channel*.

Unlike centralized cooperative sensing, the second approach Distributed cooperative sensing does not rely on a FC for making the cooperative decision.

In this case, CR users communicate among themselves and converge to a unified decision on the presence or absence of PUs by iterations. Figure 3(b) illustrates the cooperation in the distributed manner. After local sensing, CR1–CR5 shares the local sensing results with other users within their transmission range. Based on a distributed algorithm, each CR user sends its own sensing data to other users, combines its data with the received sensing data, and decides whether or not the PU is present by using a local criterion. If the criterion is not satisfied, CR users send their combined results to other users again and repeat this process until the algorithm is converged and a decision is reached. In this manner, this distributed scheme may take several iterations to reach the unanimous cooperative decision.

In addition to centralized and distributed cooperative sensing, the third scheme is relay-assisted cooperative sensing. Since both sensing channel and report channel are not perfect, a CR user observing a weak sensing channel and a strong report channel and a CR user with a strong sensing channel and a weak report channel, for example, can complement and cooperate with each other to improve the performance of cooperative sensing. In Figure 3(c), CR1, CR4,

**Figure 3: Classification of Cooperative Sensing a) Centralized b) Distributed c) Relay Assisted**



and CR5, who observe strong PU signals, may suffer from a weak report channel. CR2 and CR3, who have a strong report channel, can serve as relays to assist in forwarding the sensing results from CR1, CR4, and CR5 to the FC. In this case, the report channels from CR2 and CR3 to the FC can also be called *relay channels*. Note that although Fig. 3(c) shows a centralized structure, the relay-assisted cooperative sensing can exist in distributed scheme.

## CSS DATA FUSION SCHEMES

This section describes the fusion rules that are used for the comparison. There are three data fusion schemes for CSS. They are 1.Hard decision fusion 2. Soft data fusion 3.Quantized data fusion

### Hard Decision Fusion

In this scheme, each user decides on the presence or absence of the primary user and sends a one bit decision to the data fusion center. The main advantage of this method is the easiness the fact that it needs limited bandwidth. When binary decisions are reported to the common node, three rules of decision can be used, the “and”, “or”, and majority rule.

Assume that the individual statistics $\Delta_k$ are quantized to one bit with $\Delta_k = 0, 1$; is the hard decision from the k[th] CR user. 1 means that the signal is present, and 0 means that the signal is absent.

The **AND** rule decides that a signal is present if ***all*** users have detected a signal. The cooperative test using the AND rule can be formulated as follows:

$$H_1 : \sum_{k=1}^{K} \Delta_k = K$$

$$H_0 : Otherwise$$

The **OR** rule decides that a signal is present if ***any*** of the users detect a signal. Hence, the cooperative test using the OR rule can be formulated as follows:

$$H_1 : \sum_{k=1}^{K} \Delta_k \geq 1$$

$$H_0 : Otherwise$$

The third rule is the **voting** rule that decides on the signal presence if at least M of the K users has detected a signal with $1 \leq M \leq K$. The test is formulated as:

$$H_1 : \sum_{k=1}^{K} \Delta_k \geq M$$

$$H_0 : Otherwise$$

Cooperative detection probability $Q_d$ and Cooperative false alarm probability $Q_f$ are defined as;

$$Q_d = \Pr\{\Delta = 1 | H_1\} = \Pr\left\{\sum_{i=1}^{K} \Delta_k \geq M \mid H_1\right\}$$

$$Q_f = \Pr\{\Delta = 1 | H_0\} = \Pr\left\{\sum_{i=1}^{K} \Delta_k \geq M \mid H_0\right\}$$

### Soft Data Fusion

In soft data fusion, CR users forward the entire sensing result directly to the fusion center without performing any local and decision and the decision is made by combining these results at the fusion center by using appropriate combining rules such as square law combining (SLC), maximal ratio combining (MRC) and selection combining (SC). Soft combination provides better performance than hard combination, but it requires a larger bandwidth for the control channel. It also generates more overhead than the hard combination scheme.

**Square Law Combining (SLC):** SLC is one of the simplest linear soft combining schemes. In this method the estimated energy in each node is sent to the center fusion where they will be added together. Then this summation is compared to a threshold to decide on the existence or absence of the PU and a decision statistic is given by:

$$E_{slc} = \sum_{k=1}^{K} E_k$$

where denotes the statistic from the k^th CR user. The detection probability and false alarm probability are formulated as follow:

$$Q_{d.SLC} = Q_{mK}\left(\sqrt{2\gamma_{slc}}, \sqrt{\lambda}\right)$$

$$Q_{f.SLC} = \frac{r\left(mK, \frac{\lambda}{2}\right)}{r(mK)}$$

where $\gamma_{slc} = \sum_{k=1}^{K} \gamma_k$

and $\gamma_k$ is the received SNR at $k^{th}$ user.

**Maximum Ratio Combining (MRC):** the difference between this method and the SLC is that in this method the energy received in the center fusion from each user is ponderated with a normalized weight and then added. The weight depends on the received SNR of the different CR user. The statistical test for this scheme is given by:

$$E_{mrc} = \sum_{k=1}^{K} w_k E_k$$

**Selection Combining (SC):** In the SC scheme the FC selects the branch with highest SNR.

$\gamma_{sc}$ = max ( $\gamma_1$, $\gamma_2$, ..., $\gamma_k$)

### Quantized Data Fusion

Instead of sending the received signal energy values as in conventional schemes, the CRs quantize their observations according to their received signal energy and the quantization boundaries. Then, the quantized level is forwarded to the fusion centre, which sums up the entire received quantum it re-creates and compares to the fusion threshold. The optimization for both uniform and non-uniform quantization for cooperative spectrum sensing is considered. Then, the low complexity quantized approach using an approximated CDF on Hi is investigated. In these schemes, the optimization is based only on Hi in order to minimize the quantization uncertainty for the PU's signal, and hence improve the detection probability.

## CONCLUSION

In this paper we have presented a survey of various approaches and data fusion schemes of Cooperative Spectrum Sensing for Cognitive Radio Networks. The work can be elaborated by performing simulations using any of the data fusion schemes presented in this paper and optimize the performance of Cooperative Sensing to increase the probability of detection $P_d$ and reducing the probability of false alarm $P_f$.

## REFERENCES


1. Beibei Wang and Ray Liu K J (2011), "Advances in Cognitive Radio Networks: A Survey", *IEEE Journal of Selected Topics In Signal Processing*, Vol. 5, No. 1.

2. Edward Peh and Ying-Chang Liang (2007), "Optimization for Cooperative Sensing in Cognitive Radio Networks", *IEEE Communications Society*, WCNC 2007.

3. Haykin S (2005), "Cognitive radio: Brain-empowered wireless communications", *IEEE Journal Selected Areas in Communications*, Vol. 23, No. 2, pp. 201-220.

4. Ian F Akyildiz, Branden F Lo, Ravikumar Balakrishna (2011), "Cooperative Spectrum Sensing in Cognitive radio networks, A survey", Elsevier.

5. Ma J, Zhao G and Li Y (2008), "Soft Combination and Detection for Cooperative Spectrum Sensing in Cognitive Radio Networks", *IEEE Transactions on Wireless Communications 7,* Vol. 11, pp. 4502-4507.

6. Teguig D, Scheers B and Le Nir V (2012), "Data Fusion Schemes for Cooperative Spectrum Sensing in Cognitive Radio Networks", *MCC' 2012 Conference*, October.

7. Unnikrishnan J, Veeravalli V V (2008), "Cooperative Sensing for Primary Detection in Cognitive Radio", *IEEE Journal of Selected Topics in Signal Processing 2*, Vol. 1, pp. 18-27.

8. Varshney P K (1997), "Distributed Detection and Data Fusion", Springer-Verlag, New York.

9. Yucek T and Arslan H (2009), "A Survey of Spectrum Sensing Algorithms for Cognitive Radio Application", *IEEE Communications Surveys & Tutorials*, Vol. 11, No. 1, First Quarter 2009.

10. Zhang W, Mallik R and Letaief K (2008), "Cooperative Spectrum Sensing Optimization in Cognitive Radio Networks", on *Proc. IEEE Int. Conf. Commn.*, pp. 3411-3415.