Advanced Technique for Cooperative Spectrum Sensing Optimization in Cognitive Radio Network: A Survey

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Abstract*— Spectrum sensing is a key function of cognitive radio to prevent the harmful interference with licensed users and identify the available spectrum for improving the spectrum's utilization. However, detection performance in practice is often compromised with multipath fading, shadowing and receiver uncertainty issues. To mitigate the impact of these issues, cooperative spectrum sensing has been introduced to be an effective method to improve the detection performance by exploiting spatial diversity. Cooperative sensing is the most sophisticated approach in spectrum sensing depends on base of sharing information to eliminate error in spectrum sensing mechanism. While cooperative gain such as improved detection performance and relaxed sensitivity requirement can be obtained, cooperative sensing can incur cooperation overhead. The overhead refers to any extra sensing time, delay, energy, and operations devoted to cooperative sensing and any performance degradation caused by cooperative sensing. In this paper, the state of-the-art survey of cooperative sensing is provided to address the issues of cooperation method, cooperative gain, and cooperation overhead. Specifically, the cooperation method is analyzed by the fundamental components called the elements of cooperative sensing, including cooperation models, sensing techniques, hypothesis testing, data fusion, control channel and user selection, and knowledge base. The open research challenges related to each issue in cooperative sensing are also discussed. In this review paper, we have discussed the Cooperative sensing approach, different optimization techniques for spectrum searching and sharing features in cognitive radio.

***Index Terms*— cognitive radio, energy detection, Co-operative sensing, Optimization, Spectrum sensing.**

I. INTRODUCTION

The rapid growth in wireless communications has contributed to a huge demand on the deployment of new wireless services in both the licensed and unlicensed frequency spectrum. However, recent studies show that the fixed spectrum assignment policy enforced today results in poor spectrum utilization. To address this problem, cognitive radio (CR) [1,2] has emerged as a promising technology to enable the access of the intermittent periods of unoccupied frequency bands, called white space or spectrum holes, and thereby increase the spectral efficiency. The fundamental task of each CR user in CR networks, in the most primitive sense, 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 [1–4]. The objectives of spectrum sensing are twofold: 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 the spectrum holes for required throughput and quality-of service (QoS). Thus, the detection performance in spectrum sensing is crucial to the performance of both primary and CR networks.

The detection performance can be primarily determined on the basis of two metrics: probability of false alarm, which denotes the probability that a PU is present when the spectrum is actually free, and probability of detection, which denotes the probability that a PU is present when the spectrum is indeed occupied by the PU. Since a miss in the detection will cause the interference with the PU and a false alarm will reduce the spectral efficiency, it is usually required for optimal detection performance that the probability of detection is maximized subject to the constraint of the probability of false alarm.

Fig.1 shows the spectrum access technique, it is a way to overcome the spectrum management and improve the efficiency. A spectrum hole or white space is band of frequencies assigned to a primary user but at a specific time and particular geographic area, the band is not being utilized by that user. These white spaces can occur in two fashions, in time or in space. When a primary user is not transmitting at a given specific time, then there is a temporal spectrum hole, if a primary user is transmitting in a certain portion of the spectrum but it is too far away from the secondary user so that the secondary user or cognitive user can reuse the frequency, then a spatial spectrum hole exists. The main concept of the cognitive radio is to continuously monitor the radio spectrum, detect the occupancy of the spectrum and then opportunistically use spectrum holes with minimum interference with primary user. [5] - [7].

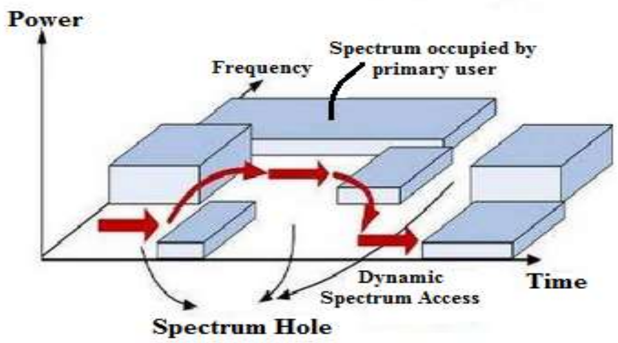

Fig.1: Spectrum Hole Concept

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The main idea of cooperative sensing is to enhance the sensing performance by exploiting the spatial diversity in the observations of spatially located CR users. By cooperation, CR users can share their sensing information for making a combined decision more accurate than the individual decisions [8]. The performance improvement due to spatial diversity is called cooperative gain. The cooperative gain can be also viewed from the perspective of sensing hardware. Owing to multipath fading and shadowing, the signal-to-noise ratio (SNR) of the received primary signal can be extremely small and the detection of which becomes a difficult task. Since receiver sensitivity indicates the capability of detecting weak signals, the receiver will be imposed on a strict sensitivity requirement greatly increasing the implementation complexity and the associated hardware cost. More importantly, the detection performance cannot be improved by increasing the sensitivity, when the SNR of PU signals is below a certain level known as a SNR wall [9]. Fortunately, the sensitivity requirement and the hardware limitation issues can be considerably relieved by cooperative sensing.

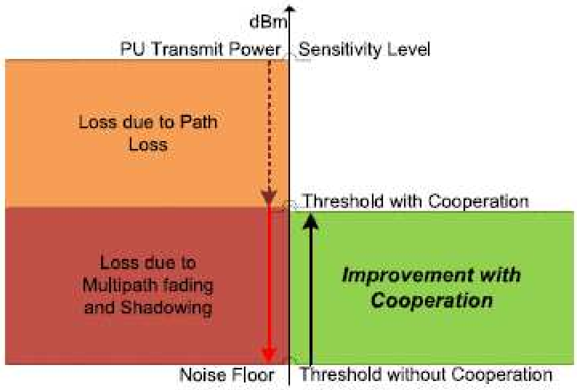

Fig. 2: Improvement of sensitivity with cooperative sensing

As shown in Fig. 2, the performance degradation due to multipath fading and shadowing can be overcome by cooperative sensing such that the receiver's sensitivity can be approximately set to the same level of nominal path loss without increasing the implementation cost of CR devices. However, cooperative gain is not limited to improved detection performance and relaxed sensitivity requirement. For example, if the sensing time can be reduced due to cooperation, CR users will have more time for data transmission so as to improve their throughput.

In this case, the improved throughput is also a part of cooperative gain. Thus, a well-designed cooperation mechanism for cooperative sensing can significantly contribute to a variety of achievable cooperative gain.

In [10], Cabric et al. identified the ''three main questions regarding cooperative sensing'' as follows [10]

- How can cognitive radios cooperate?
- How much can be gained from cooperation?
- What is the overhead associated with cooperation?

These three questions surrounding the issues of Cooperation Method, Cooperative Gain, and Cooperation Overhead, respectively, should be addressed in every cooperative sensing scheme. In this paper, we aim to survey the state of-the-art research in cooperative sensing centering these three issues by first analyzing the cooperation method with the fundamental components of cooperative sensing and then presenting the impacting factors of achievable cooperative gain and incurred cooperation overhead. In addition, we identify open research challenges related to each issue in cooperative sensing along with the discussion.

CR has following function which is very essential for spectrum sensing. [4]

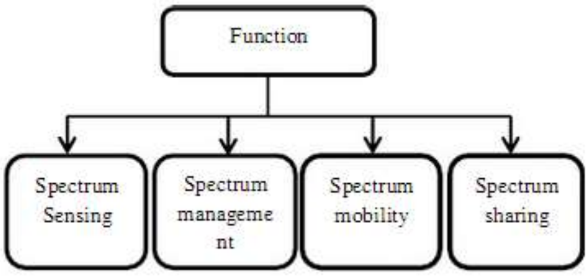

Fig. 3: Cognitive Radio Function

- Spectrum sensing detects the unused spectrum/spectrum hole of licensed spectrum or user and determining if a primary user is present, detecting the spectrum hole.
- Spectrum management is a process of CR in which it captures the best suitable spectrum which is fulfills the communication requirement of user.
- Spectrum mobility is the case when a secondary user speedily allocates the channel or spectrum band to the primary user when a primary user wants to retransmit again.
- Spectrum sharing is a process in which the best suitable channel having coordination with others.

II. TAXONOMY AND FRAMEWORK OF COOPERATIVE SENSING

Here, we present the problem of the primary signal detection in cooperative sensing and introduce the classification and the framework of cooperative sensing.

A. *Primary signal detection*

The process of cooperative sensing starts with spectrum sensing performed individually at each CR user called local sensing. Typically, local sensing for primary signal detection can be formulated as a binary hypothesis problem as given below,

$$x(t) = \begin{cases} n(t), & H0 \\ h(t) * s(t) + n(t) & H1 \end{cases} \quad (1)$$

Where x(t) denotes the received signal at the CR user, s(t) is the transmitted PU signal, h(t) is the channel gain of the sensing channel, n(t) is the zero-mean additive white Gaussian noise (AWGN), H0 and H1 denote the hypothesis of the absence and the presence, respectively, of the PU signal in the frequency band of interest. For the evaluation of the detection performance, the probabilities of detection Pd and false alarm Pf are defined as [11]

$$P_d = P\{decision = H1|H1 = P\{\gamma > \lambda \,|H1\} \quad (2)$$
$$P_f = P\{decision = H1|H0 = P\{\gamma > \lambda \,|H0\} \quad (3)$$

Where Y is the decision statistic and λ is the decision threshold. The value of λ is set depending on the requirements of detection performance. Based on these definitions, the probability of a miss or miss detection is defined as

$$P_m = 1 - Pd = P\{decision = H0|H1 \quad (4)$$

The plot that demonstrates Pd versus Pf is called the receiver operating characteristic (ROC) curve, which is the metric for the performance evaluation of sensing techniques. In cooperative sensing, the probabilities of detection and false alarms for evaluating the performance of cooperative decisions are denoted by Qd and Qf , respectively.

B. Classification of Cooperative Sensing

To facilitate the analysis of cooperative sensing, we classify cooperative spectrum sensing into three categories based on how cooperating CR users share the sensing data in the network: centralized [10,6,11], distributed [12], and relay-assisted [13–15]. These three types of cooperative sensing are illustrated in Fig. 3.

Fig.3: Classification of cooperative sensing: (a) Centralized, (b) Distributed, and (c) Relay-assisted

In centralized cooperative sensing, a central identity called fusion center (FC)[2] 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. As shown in Fig. 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. Note that centralized cooperative sensing can occur in either centralized or distributed CR networks. In centralized CR networks, a CR base station (BS) is naturally the FC. Alternatively, in CR ad hoc networks (CRAHNs) where a CR BS is not present, any CR user can act as a FC to coordinate cooperative sensing and combine the sensing information from the cooperating neighbors.
Unlike centralized cooperative sensing, 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. Fig. 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 Fig. 3(c), CR1 CR4, 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. In fact, when the sensing results need to be forwarded by multiple hops to reach the intended receive node, all the intermediate hops are relays. Thus, if both centralized and distributed structures are one-hop cooperative sensing, the relay-assisted structure can be considered as multi-hop cooperative sensing.

C. Structure of Cooperative Sensing

The framework of cooperative sensing consists of the PUs, cooperating CR users including a FC, all the elements of cooperative sensing, which will be introduced in next section, the RF environment including licensed channels and control channels, and an optional remote database. Fig. 4 illustrates the framework of centralized cooperative sensing from the perspective of the physical layer. In this framework, a group of cooperating CR users performs local sensing with an RF frontend and a local processing unit. The RF frontend can be configured for data transmission or spectrum sensing. In addition, the RF frontend includes the down-conversion of RF signals and the sampling at Nyquist rate by an analog-to-digital converter (ADC). The raw sensing data from the RF frontend can be directly sent to the FC or be locally processed for local decision.

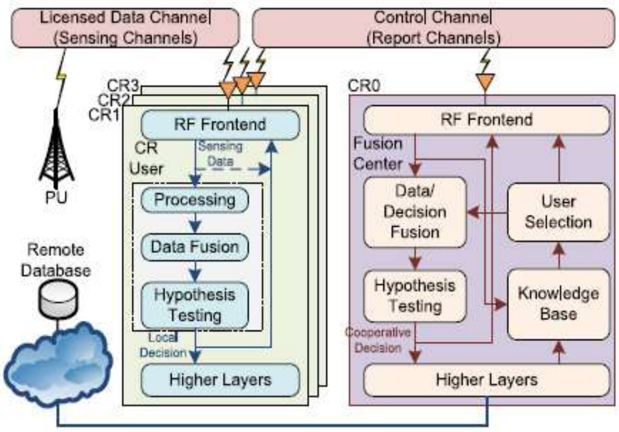

Fig. 4: structure of centralized cooperative sensing

To minimize the bandwidth requirement of the control channel, certain local processing is usually required. The processing includes the calculation of test statistics, and a threshold device for local decision. Once the raw sensing data or the local decisions are ready, a medium access control (MAC) scheme is required to access the control channel for reporting the sensing results. The sensing results may also be used by higher network protocol layers for spectrum-aware routing selection [16] for example. The FC in the framework is a powerful CR user, which includes all the capabilities of a regular CR user and the additional user selection capability with the assistance of a embedded knowledge base. If the FC is as powerful as a base station, it may have the connection to the remote database for PU activity and white space information. For the framework of distributed cooperative sensing, all CR users are essentially the same and similar to the FC in the framework of centralized cooperative sensing with an optional and smaller knowledge base for local use.

III. COOPERATIVE SPECTRUM SENSING(CSS)

Cooperative spectrum sensing is a method in, which multiple cognitive radios collaborate or cooperate to each other either by sending their decisions statistics to a common node and the final decision is made by the base station. This sensing is more powerful than others because it can overcome the hidden terminal problem, which occurs when a PU‟s is shadowed by an obstacle, so that the cognitive user or SU‟s can't detect it, resultant of this cause high interference with PU‟s. [8]
The major challenges of cooperative spectrum sensing are applying best optimization and increased complexity. Cooperative can be implemented in two way- centralized cooperative sensing, distributed cooperative sensing.

A. Centralized sensing

In centralized cooperative sensing, a central unit is present which collect all sensing information from cognitive devices or secondary user and identifies available spectrum, then broadcast this sensing information to other secondary user without causing any interference. This central unit or fusion Centre makes a global decision that the PU is present in the channel. The crucial task of the centralized sensing is to mitigate the fading effects of the various channels and increase detection performance. [9]

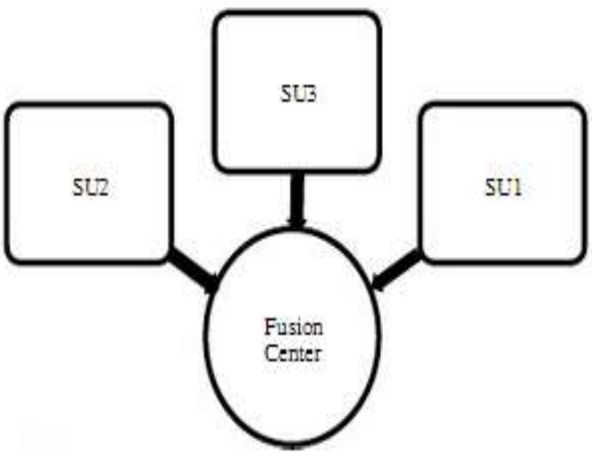

Fig. 5: centralized cooperative sensing

B. Distributed cooperative sensing

Distributed sensing has one more advantage over centralized sensing, there is no need for a backbone infrastructure and it reduced cost. Collaboration is performed between two or more cognitive user. The main concept of distributed sensing is secondary user share their sensing information among themselves. Only final decision is shared in order to minimize the network overhead due to collaboration. This method can improve the sensing performance as well as detection capability of system.

The conventional cooperative sensing is generally considered as a three-step process: local sensing, reporting, and data fusion. In addition to these steps, there are other fundamental components that are crucial to cooperative sensing. We call these fundamental and yet essential components as the elements of cooperative sensing. In this section, we analyze and present the process of cooperative sensing by seven key elements: (i) cooperation models, (ii) sensing techniques, (iii) control channel and reporting, (iv) data fusion, (v) hypothesis testing, (vi) user selection, and (vii) knowledge base. As shown in Fig. 6, these elements are briefly introduced as follows:

1. Cooperation Models: Cooperation models consider the modeling of how CR users cooperate to perform sensing. We consider the most popular parallel fusion network models and recently developed game theoretical models.
2. Sensing Techniques: 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. The choice of the sensing technique has the effect on how CR users cooperate with *each other.*

Fig. 6: Elements of cooperative spectrum sensing

3. Hypothesis Testing: 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.
4. Control channel and Reporting: Control channel and reporting concern 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 via the bandwidth-limited and fading-susceptible control channel.

5. Data Fusion: Data fusion is the process of combining the reported or shared sensing results for making the cooperative decision. Based on their data type, the sensing results can be combined by signal combining techniques or decision fusion rules.
6. User Selection: User selection deals with how to optimally select the cooperating CR users and determine the proper cooperation footprint/range to maximize the cooperative gain and minimize the cooperation overhead.
7. Knowledge Base: Knowledge base stores the information and facilitates the cooperative sensing process to improve the detection performance. The information in the knowledge base is either a priori knowledge or the knowledge accumulated through the experience. The knowledge may include PU and CR user locations, PU activity models, and received signal strength (RSS) profiles.

IV. SPECTRUM SENSING

One of the most important elements in the CR network is spectrum sensing [6].when we decreasing the optimal threshold value to decrees the probability of missed detection also increase the probability of false alarm and when increasing the threshold value to probability of false alarm would increase the probability of missed detection.
Since both are unwanted and both can"t be deceased simultaneously. Many different signal detection techniques can be used in spectrum sensing to improve the detection probability.Fig.6 gives classification of the Spectrum Sensing.

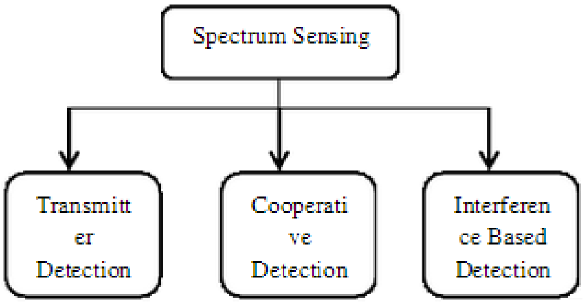

Fig. 6: Classification of spectrum sensing technique

The cognitive radio should describe between used and unused spectrum bands. In spectrum sensing Transmitter detection method is based on the detection of the weak signal from a primary transmitter through the different techniques:

A. *Energy detection based spectrum sensing*

Energy detector is a non-coherent method of spectrum sensing and it is used to detecting the primary user signal in the frequency spectrumbeing sensed. Energy detection sensing method is more popular because it does not require any prior information of primary signal and it is simple. The energy detector performance is robust in nature. [1]-[7]

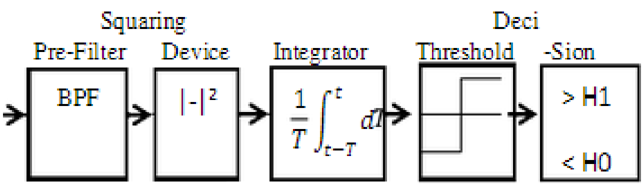

Fig.7: Energy Detector Block Diagram

Fig.6 displays the traditional energy detector. ED consists of a band pass filter or pre-filter matched to the bandwidth of the signal is required in the time domain representation. Time domain representation is inflexible compare to the other. So it is crucial to use the frequency representation for analyzing received signal. Then the output of BPF is fed to the squaring block this block consisting one squaring device followed by a finite time integrator. ED is also known as Blind signal detector as the characteristic of the signal is ignored by it. All wireless transmitters has an energy as:

$$M = \sum_{n=0}^{N} |Y(n)|^2 \quad (5)$$

Where, N is the size of observation vector. The decision that the band are occupied can be obtained by following two hypotheses-

$$H0: \quad Y(K) = n(K) \quad (6)$$
$$H1: \quad Y(K) = h * S(K) + n(K) \quad (7)$$

Where Y (k) is the received signal by the secondary user at each instant k and n (k) is the noise of variances σ^2. The “probability of primary user detection” and the “probability of false alarm” can be calculated by the given equation –

$$P_d = P\left[y > \frac{\lambda}{H1}\right] = Q_m(\sqrt{2\gamma}, \sqrt{\lambda}) \quad (8)$$
$$P_f = P\left[y > \frac{\lambda}{H0}\right] = \Gamma(m, \tfrac{\lambda}{2})/\Gamma(m) \quad (9)$$

Where,
λ=SNR of the system
$\Gamma(.)$=complete gamma function
N= TW (time bandwidth product)
$\Gamma(\ldots.)$ = Incomplete gamma function
Q_m= Generalized Marcum Function

The advantage of the ED, it is easy to implement, computational complexity is low, and no need to priori information of primary user. One of the major disadvantage of ED is that it does not perform well in low SNR condition.

B. *Matched Filter Detector*

Matched filter is designed to maximize the output SNR for a given signal. Matched filter detection required prior knowledge of the primary user. In matched filter detection convolution between unknown signal is done with the filter whose impulse response is time shifted. The expression for matched filter is expressed as

$$Y(m) = \sum_{k=-\infty}^{\infty} x[k]h[m-k]$$

Where x is the unknown signal (h) of matched filter that is matched to the reference signal is convolved with it for maximizing the SNR. [7]

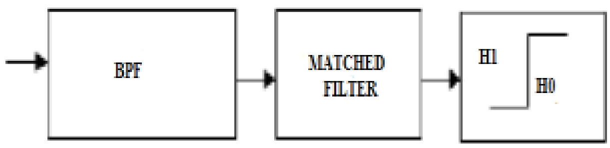

Fig.8: MFD Block Diagram

Advantage-
- Since it maximizes the SNR, it is desirable detector.
- The sensing time is slow as compare to other detectors.

Disadvantage-

- Prior knowledge of the PU signal is required.

C. Cyclo Stationary Feature Based

spectrum sensing cyclo stationary feature detection uses the built in periodic component/feature of the modulated signal (carrier). The periodicity is commonly encapsulated in sinusoidal carrier, pulse train, spreading code, hopping sequence of the primary signal. A wide sense stationary process that shows cyclo stationary has both mean and auto-correlation function in time domain. In the cyclo stationary feature detection requires the prior knowledge of the signal and the synchronization is not necessary in case of cooperative sensing. The main disadvantage of the Cyclo stationary feature detection is its long sensing time and high computational complexity. Thus Cyclo stationary method is more robust to noise and perform better then energy detection in low SNR condition.

D. Wavelet Based Spectrum Sensing

Waveform Based Spectrum Sensing method is applicable when the system known signal patterns only. These known pattern are used for synchronization .This pattern include preambles, spreading sequences, midambles etc. Waveform Based Spectrum Sensing is more reliable and robust than other method. This method does not require any prior information of the system

V. Data Fusion

In cooperative sensing, data fusion is a process of combining local sensing data for hypothesis testing, which is also an element of cooperative sensing. Depending on the control channel bandwidth requirement, reported sensing results may be of different forms, types, and sizes.

In general, the sensing results reported to the FC or shared with neighboring users can be combined in three different ways in descending order of demanding control channel bandwidth: (i) Soft Combining: CR users can transmit the entire local sensing samples or the complete local test statistics for soft decision. (ii) Quantized Soft Combining: CR users can quantize the local sensing results and send only the quantized data for soft combining to alleviate control channel communication overhead. (iii) Hard Combining: CR users make a local decision and transmit the one bit decision for hard combining. Obviously, using soft combining at the FC can achieve the best detection performance among all three at the cost of control channel overhead while the quantized soft combining and hard combining require much less control channel bandwidth with possibly degraded performance due to the loss of information from quantization. In this subsection, we first discuss soft combining and quantized soft combining techniques, and then focus on the fusion rules for decision fusion when the hard combining is used.

Soft Combining and Quantized Soft Combining

Existing receiver diversity techniques such as equal gain combining (EGC) and maximal ratio combining (MRC) can be utilized for soft combining of local observations or test statistics. In [61], an optimal soft combination scheme based on NP criterion is proposed to combine the weighted local observations. The proposed scheme reduces to EGC at high SNR and reduces to MRC at low SNR. Since such a soft combining scheme results in large overhead, a softened two-bit hard combining scheme is also proposed in [18] for energy detection. In this method, there are three decision thresholds dividing the whole range of test statistics into four regions. Each CR user reports the quantized two-bit information of its local test statistics. This method shows the comparable performance with the EGC scheme with less complexity and overhead.

Hard Combining and Decision Fusions

CSS deals with the hard decision and soft decision combining techniques. Totally there are six fusion rules are presented in the literature they are soft Optimal Linear mixing, Likelihood Ratio combining, soft Equal Weight combining, and hard decision combined with the AND, OR, and the MAJORITY counting rules. Because of simplicity most famous combining technique is hard decision combining contains OR, AND, and the Majority counting rules. In the implementation of hard decision rules, the fusion centre or central unit produce an n out of M rule that decides on the hypothesis testing at the secondary user. Whenever one secondary user sends output as one i.e., H1, then it comes under OR logic rule similarly if all the secondary users send output as one then it comes under AND logic rule. If majority secondary users send the decision as one then it comes under MAJORITY rule. Assuming uncorrelated decisions, the probability of detection, probability of false alarm and probability of miss detection at the fusion centre are given by [16]:

$$Q_f(K) = \sum_{j=n}^{K}\binom{K}{j} P_f^j (1 - P_f)(1 - P_f)^{k-j} \tag{10}$$

$$Q_m(K) = 1 - \sum_{j=n}^{K}\binom{K}{j} P_{d^j} (1 - P_d)^{k-j} \tag{11}$$

$$\mathrm{Q_m(K) = 1 - Q_m(K)} \tag{12}$$

OR Rule:

OR rule is implemented when the sensing threshold is high and thus only one or very few cognitive radios decision is considered for fusion. Performance of detection in CSS using this rule can be calculated by putting n=1 in the above Equations:

$$Q_d(K) = 1 - \prod_{i=1}^{k}(1 - P_{d,i}) \tag{13}$$
$$Q_f(K) = 1 - \prod_{i=1}^{k}(1 - P_{f,i}) \tag{12}$$
$$Q_m(K) = 1 - Q_d(K) \tag{13}$$

AND Rule:

AND rule is implemented when the sensing threshold is low, and at that time all the cognitive radios decision is considered for fusion. Performance of detection in CSS using this rule will be calculated by putting n=N in the above equations:

$$Q_d(K) = P_{d,i^K} \tag{14}$$
$$Q_f(K) = P_{f,i^K} \tag{15}$$
$$Q_m(K) = 1 - Q_d(k) \tag{16}$$

MAJORITY Rule:

The MAJORITY rule is implemented when more than half of the cognitive radios decision is considered for fusion. Performance of detection in CSS using this rule can be calculated by putting n= $\lfloor N/2 \rfloor$ in the above equations:

$$Q_{d,maj} = \sum_{\lfloor \frac{N}{2} \rfloor}^{N} \binom{N}{K} P_d j \, (1 - P_d)^{K-j} \quad (17)$$

$$Q_{f,maj} = \sum_{\lfloor \frac{N}{2} \rfloor}^{N} \binom{N}{K} P_f j \, (1 - P_f)^{K-j} \quad (18)$$

$$Q_m (K) = 1 - Q_d (K) \quad (19)$$

It can be observed in (5) and (6) that when the value of k is taken as 1 and N, the k out of N rule becomes the OR and AND rules, respectively. The OR rule works best when the number of cooperating CR users is large. Similarly, the AND rule works well when the number of cooperating users is small. The majority rule can be obtained from the k out of N rule under the condition when k ≥ N/2. Thus, it is important to determine the optimal value of k for which the detection errors are minimized. It can be shown that the optimal value of k depends on the detection threshold. For a small fixed threshold, the optimal rule is the AND rule, i.e., k = N. Similarly, for a fixed very large threshold, the OR rule (k = 1) is said to be optimal. The k out of N rule is also equivalent to Counting Rule or Voting Rule when the threshold for determining H1 equals k. In [19], the proposed cooperative sensing scheme uses the k out of N rule for data fusion at the FC. The optimal value of k and the optimal sensing time are obtained by optimizing the average achievable throughput subject to the detection performance.

VI. INTERFERNCE SPECTRUM SENSING SCHEME

This scheme of sensing differs from the typical study of interference that is generally transmitter centric. Typically, a transmitter controls its interference by regulating its out-of-bound transmission and its output transmission power; depend upon its location from other users. This scheme of sensing mainly concentrates on measuring interference on the receiver side. The FCC introduces interference temperature, a new model of measuring interference. With the help of interference temperature limit, which indicate the amount of interference that the receiver can tolerate, interference can manage. As long as the data transmission of SU does not exceed the interference temperature limit they can use the particular radio spectrum band. The main problem with this scheme is that, for interference measurement SU should be aware about the exact location of the PU.

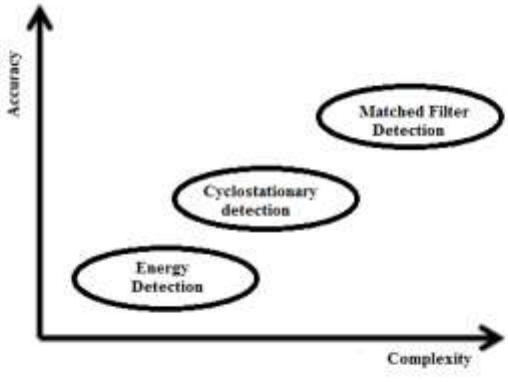

Fig.9: Comparison of sensing scheme

VII. CONCLUSION

A survey of different types of spectrum sensing such as cooperative, transmitter based and interference based spectrum sensing has been carried out.

The Cooperative sensing is an effective technique to improve detection performance by exploring spatial diversity at the expense of cooperation overhead. In this paper, we dissect the cooperative sensing problem into its fundamental elements and investigate in detail how each element plays an important role in cooperative sensing. Moreover, we define a myriad of cooperation overheads that can limit the achievable cooperative gain. We further identify the research challenges and unresolved issues in cooperative sensing that may be used as the starting point for future research.

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