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Spectrum Sensing: Key to Cognition

(Classification, Implementation, Challenges and Research directions)

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Abstract: Cognitive Radio (CR) significantly improve spectrum utilization through dynamic spectrum access (DSA). Efficient utilization of the unused or partially used spectrum for providing opportunistic access to secondary users (SU) is the main function of CR. CR has to sense continuously radio environment and keep on adjusting its transmission parameters for opportunistic transmission without causing harm to primary user (PU). In This paper a detailed description of CR is presented, various spectrum sensing (SS) technique aredescribed along with their implementation issues and various problem are highlighted to recognize future research trends.

Keywords: Cognitive Radio (CR); Spectrum Sensing (SS); Dynamic spectrum access (DSA); Next generation networks; Spectrum management.

I. INTRODUCTION

CR [1] has been developed as a new paradigm for enabling much higher spectrum utilization, providing more trustworthy and personal radio services, reducing harmful interference and supporting convergence of different wireless communication networks.The original definition of CR has seen been changed in many wayssince it was coined by Mitola and Maguire back in 1999as "CR is considered as a goal towards which a software defined radio platform should evolve a fully reconfigurable wireless transceiver which automatically adapts its communication parameters to network and user demands[2]".All the deviated definitions have somecommon point, these are"environmental awareness information (such as spectrum sensing)", "parameter re-configurability", and "intelligent adaptive behavior" [3]. Definition given by ITU-R is "CR as a technology whichobtain knowledge of its operational and geographical environment, established policies and its internal state anddynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained [4]".

The importance of the CR revels from the fact, it efficiently utilize spectrum which is a very important resource and is ill utilized. This Spectrum shortage in turn causes hurdle in deployment of new emerging wireless technologies. According to FCC spectrum utilization varies from 15% to 85% [5, 6]. Spectrum utilization as a function of frequency has been shown in figure 1[7]. From the discussion so far it can be concluded that spectrum shortage is not due to limited spectrum itself but is due to poor utilization. CR technology enables efficient utilization of radio resources by providing opportunistic access to SU. There are two integral things connected with CR, ability to sense radio environment and reconfigure transmission parameters according to operating environment. For reliable sensing operation high sensitivity and high degree of flexibility required which also impose constraint on implementation of spectrum sensing hardware in CR [8].

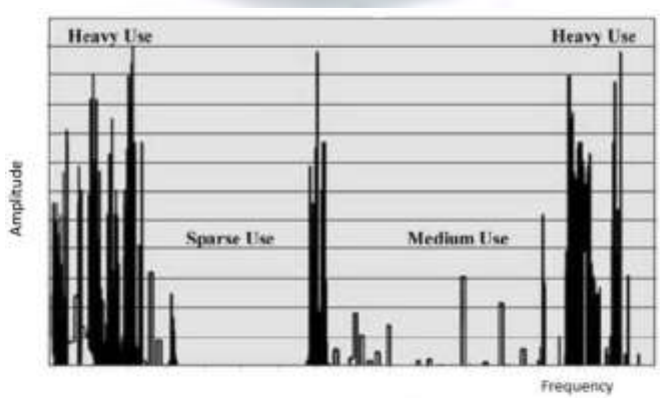

Figure 1: Spectrum utilization as a function of frequency.

Since CRor SU are considered lower priority in spectrum allocated to a primary user, anessential requirement is to avoid interference PU in their proximity. As, PU innetworks have no requirement to change their infrastructure for spectrum sharing with cognitive networks. Therefore, cognitive radios should be capable to independently detect PU presence through continuous spectrum monitoring. Different classes of primary users would require different sensitivity and rate of sensing for the detection. For example, TV broadcast signals areeasier to detect than GPS signals, as TV receivers' sensitivity is ten dB poorer than GPS receiver [8].

In general, cognitive radio sensitivity should outperform PU receiver by a large margin in order to avoid hidden terminal problem. This is the fundamentalissue that makes SS very challenging research problem. Achieving sensitivity requirement of each primary receiver with a wideband radio would be difficult enough, but additional 30-40db margin requirement create huge problem as no direct measurement of a channel between PUreceiversis possible. In such cases decision is based upon local channel measurement to a PU transmitter. Other major issue are disused in the later part of paper along with technology details.

The implementation of the SS function also requires a high degree of flexibility since the radio environment is highly variable, both because of different types of PU systems, propagation losses, and interference.
As a result of limited available spectrum and inefficiency spectrum utilization necessitate a new communication approach to be implemented in existing wireless networks. This new networking paradigm is known as Next Generation Networks.

CR in Next generation Networks

CR is main component of Next generation networks .The main function of CR in net generation network are listed below:

- SS: Detecting and sharing unused frequency band.
- Spectrum management: Picking up the available spectrum for opportunistic user.
- Spectrum mobility: Ensuring continuous communication requirements of SU.
- Spectrum sharing: Maintain spectrum schedule for coexisting no of SUs.

These function are accomplished by lower two network layer in CR, and is shown in figure 2

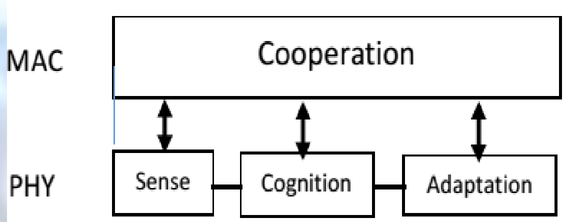

Figure 2: Network layer functionalities related to spectrum sensing

This paper basically presents an overview of CR technology. Section I introduces cognitive radio, overview of implementation issues and function of CR in next generation wireless networks. Section II includes cognitive characteristics and capabilities depending upon which spectrum access model are being derived. Section III contains detailed classification of SS technique along with implementation issues. Section IV points out some challenges in SS. Open research direction are presented in section V and various aspects of paper are concluded in Section VI.

II. COGNITIVE RADIO

CR is essentially an evolution of software defined radio (SDR) which is formally defined by FCC [9] as a ''Cognitive Radio (CR)'' is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. Three key aspects of a CR are:

• Sensing – A CR must be able to identify the unused spectrum frequency band.
• Flexible – A CR must be able to change signal frequency and spectrum shape to fit into the unused spectrum of frequency.
• Non-interfering – ACR must not cause harmful interference to the PU.

The ultimate objective of CR is to make efficient use of the unused spectrum. This means that CR introduces intelligence to SDR such that it searches for a spectrum hole defined as ''a licensed frequency band not being used by an licensed user at that time within a selected area [10]''. As most of the spectrum is already assigned to PUs, the key goal is to share licensed spectrum without producing harmful interference to PUs. Now it can be concluded that main functionality of CR is to keep on searching for spectrumhole [10]. Free spectrum band isopportunity exploited by CR as long as no PU activity is detected. If frequency band is again acquired by PU, CR being low-priority SU has to either vacate band or adjust its transmission parameters to another spectrum hole if available.

Characteristics of Cognitive Radio

Cognitive functionality described above is achieved by two main characteristics of CR, cognitive capability and reconfigurability. Cognitive capability is ability of radio to interact with its real time radio environment to identify un-occupied licensed spectrum bands called spectrum holes [11]. According to observations published by FCC in [6], spectrum holes can be classified into two groups: temporal spectrum holes and spatial spectrum holes. Based upon thesetwo secondary communication schemes [12] of opportunistic spectrum utilization in time and space domain can be described which are represented in in Fig. 3and 4 respectively.

A temporal spectrum hole i.e. time based occurs when no primary transmission is detected over the interested frequencyband for a specific period of time and hence this frequency band is available for SUin that time slot. A spatial spectrum hole i.e. space based is generated when the primarytransmissions are confined to a certain area as shown in Fig. 4 and hence this frequency band is available for SU (it may occur in same time slot as well) well outside the coverage area of PU to avoid any possible interference with PUcommunication. The secondary transmission over the spatially available licensed spectrum is allowed if it cause no interference with PU. This puts astrict requirement on SU to be able to effectively detect PU at any place where SU may cause interference to primary transmission. Therefore, a safeguard area of PU is defined wherein SU must be able to detect any PU activity to avoid interference with primary receiver D_{min}apart from SU [13, 14]. The cognitive capability is not only for monitoring power in some frequency band rather it demands great care of other parameters as well i.e. multidimensional spectral awareness [15].This requires that CR should be able to modifyits transmission parameters in order to adapt to its changing radio environment, this characteristic of CR is called reconfigurability.

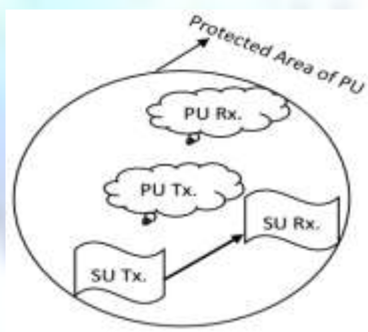

Figure 3: Temporal spectral hole

Cognitive Capabilities

Capability of CR to capture or sense are required to support DSA. A SU with such a capability is called CR [16, 17] or a CR user. Cognitive capability is to find out spectrum holes at a specific time or location by real time interaction of radio environment. The spectrum holes can be classified as [18]

- Black holes: these are occupied by high-power interferers and should be always avoided.
- Grey holes: these are partially occupied by low-power interferers.
- White holes: which are free of RF interferers except for ambient noise, made up of natural and artificial forms of noise.

There are different types of cognitive capabilities with which a CR may be equipped. Such as,

- CR may sense or monitor the ON/OFF status of the PUs [16, 19].
- CR can predict the interference power level that is received at the primary Rx [19].
- CR may also acquire the messages that are transmitted by the primary Tx [20].

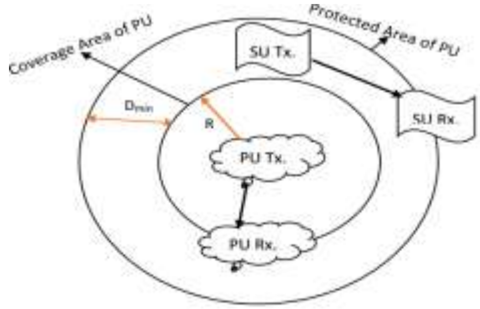

Figure 4: Spatial spectral hole

The process of acquiring the radio environment knowledge can be complex and expensive, because it may involve spectrum sensing, autonomous learning, user cooperation, modeling, and reasoning. Depending upon cognitive capabilities, a CR may access the radio spectrum in different ways. Two main models are described in detail in literature so far. 1) Theopportunistic spectrum access(OSA) model and 2) theconcurrent spectrum access(CSA) model.

The OSA model is diagrammatically represented in Fig. 5. In this model, spectrum sensing is carried out to find out spectrum hole [10]. Upon detecting one or multiple spectrum holes, the CR reconfigures its transmission parameters (e.g. carrier frequency, bandwidth and modulationscheme) to operate in the identified spectrum holes.

Whiledoing so, the CR user needs to frequently monitor the spectrumon which it operates and quickly vacate it whenever the PUs become active. This method of spectrum access was first proposed by Mitola in [16, 17], under the name spectrum pooling. The term opportunistic spectrum accesswas coined inNext-Generation Communications (XG) Program by Next-Generation Communications (XG) Program.

The CSA model is presented in Fig. 6, where a CR user coexists with an active PU in a licensed band provided transmitting power of CR Tx. is below a tolerable threshold. Here g0 and g1 are path gain of CR transmitter to PU receiver and CR receiver respectively. This model requires the CR Tx. to predict the interference power level and keep its transmission power belowthreshold value. This approach is also termed as spectrum sharingin [19] and spectrum underlay in [21].

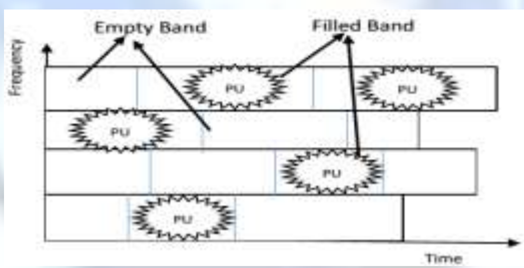

Figure 5: OSA model: CR users opportunistically access the spectrum holes

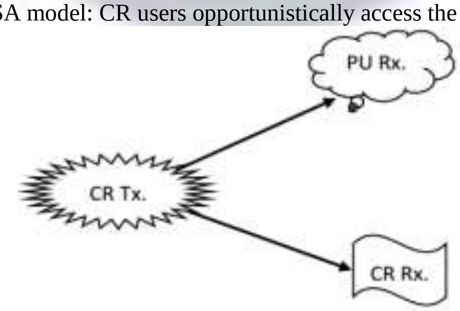

Figure 6: CSA model: CR users coexist with active PUs under the interference power constraint

III. SPECTRUM SENSING TECHNIQUE AND IMPLEMENTATION ISSUES

In this section based upon fundamental approach classification of SS technique is done. Implementation issue are considered along description of each class.

Fundamental approach

The main function of SS is to obtain information about spectrum occupancy. There are basically two approach based upon which decision about the presence of PU can be made, these are spectrum overlay and spectrum underlay.

In spectrum overlay approach SUs only transmit over the licensed spectrum when there is no PUs in that band i.e. spectrum is free. Decision about presence or absence of PU can be made by a single CR or by a group of CRs. Single CR decision making approach is called non cooperative primary transmitter detection where's cooperative decision referred when no of CRs combine to give their decision. Strictly speaking CR makes a decision about the presence or absence of PU on its local observations of primary transmitter signal in non-cooperative scheme where's CR makes a decision about the presence or absence of PU based upon observation of multiple CRs.

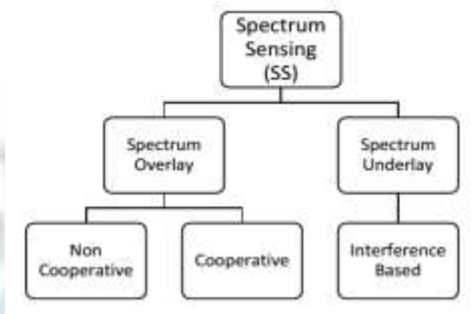

Figure 7: classification of spectrum sensing technique

In spectrum underlay SUs are allowed to transmit concurrently with PUs under the severe interference avoidance constraint.This method was analyzed and declared to be non-implementable [22].

Based on the priori information required to detect PU SS methods can be classified in three classes. These are non-blind, semi-blind or total blind. Non-blind schemes require primary signal signatures as well as noise power estimation to detect PU. Semi-blind schemes require only noise variance estimate to detect a spectrum hole in given frequency band. The most practical sensing techniques is blind, in which no information on source signal or noise power is required to determine PU.

Sensing may also be classified on the basis of application in hand. If it is required to sense large frequency range Wide Band SS (WBSS), in case of low spectrum requirement it is termed as Narrow Band SS (NBSS).

Non Cooperative sensing

To decide about the presence of PU a detection problem in term of binary hypothesis is defined as:

$$x(n) = w(n) \qquad H0 \qquad (1)$$

$$x(n) = s(n) + w(n) \qquad H1 \qquad (2)$$

Where n = 0,1,2,3... N, which represents the number of samples. x(n) is the received signal at the secondary user, s(n) is the primary user signal. There are two fold function of SS i.e. to determine presence and absence of signal and to differentiate PU and SU signals. For finding how much effective our detection scheme is performance measure are defined. Conventionally, the performance of SS scheme is determined by its sensitivity and specificity [23]which are measured in terms of probability of detection P_d and probability of false alarm P_f, respectively. P_d is the probability of correctly detecting the PU signal in the given frequency band. Mathematically it is given as

$$P_d = P_r(\text{signal is detected} \mid H1). \qquad (3)$$

$P_f$is the probability that the detection algorithm falsely decides the presence of PU in the interested band of frequencywhen it actually is absent, and it is given as

$$P_f = P_r(\text{signal is detected} \mid H0) \qquad (4)$$

In any SS scheme, for best performance P_d should be as high as possible and a lower value of Pf is desirable. One moresignificant parameter of attention is the probability of missed detection P_m which is the counterpart of P_d. $P_m$indicates the probability of not detecting the primary transmission when actually PU is present. And it can be formulated as:

$P_m = 1 - P_d = P_r$(signal is not detected|H1). (5)

If Pf and Pm are high, probability of making wrong decision increase and performance of SS technique degrades as high Pf corresponds to poor spectrum utilization/exploitation by CR and high Pm results in increased interference at primary receiver. Hence the main challenge in transmitter detection approach is to keep both Pf and Pm under certain maxima of overall system i.e. minimum value of Pf and Pm which improve total performance.

Number of methods present in literature based upon non cooperative detection, but energy detection, matched filter detection and cyclo stationary detection are important and discussed in this paper along with their implementation issues.
Energy Detection(ED)

In this method energy of received signal is compared with predetermined threshold to make decision about spectrum occupancy. Threshold is set based upon noise floor in the operating environment. This method is especially suited when CR can't gather sufficient information about PU signal i.e. in case of wideband sensing.
Critical thing in ED is to set appropriate threshold value [10, 22]. Importance of threshold setting is illustrated diagrammatically in Figure 8 which shows probability density functions of received signal in bath cases i.e. when PU is present and when PU is absent.

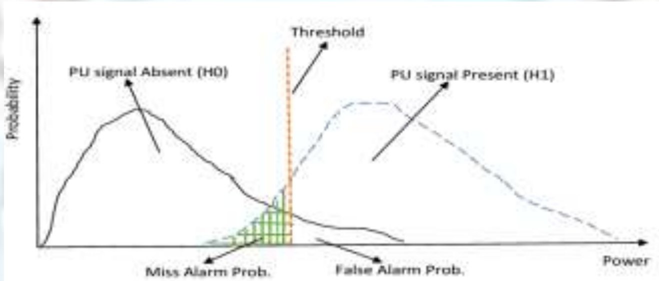

Figure 8: Importance of setting threshold

If we defined Γ as test statistics in in form of energy content of received signal, energy detection differentiates between the two hypotheses H0 and H1 by comparing Γ with predefined threshold voltage V_t as

$$\Gamma \geq V_t \Rightarrow H1$$
$$\Gamma < V_t \Rightarrow H0$$

Hence if the selected V_t is too low or move threshold in Left Hand Side (LHS) in Figure 8, the false alarm probability ($P_f = P_r(\Gamma \geq V_t|H0)$) increases resulting in low spectrum utilization. In contrast, if V_t is kept high or move threshold in Right Hand Side (RHS), the probability of missed detection ($P_m = P_r(\Gamma < V_t/H1)$) increased leading interference with PU.
Based upon how we are setting parameter there are two variation in ED. If we focus on reuse probability of unused spectrum, P_f shouldfixed to a small value (e.g. ≤5%) and P_d is maximized. This is referred to as constant false alarm rate (CFAR) detection scheme. If it is required to guarantee a given non-interference probability, P_m is set at a lowest value (or equivalently P_d is fixed to a high value (e.g. ≥95%)) and P_f is minimized. This requirement is known as constant detection rate (CDR) scheme.

Implementation

Basically it is a suboptimal non coherent technique used in radiometry.An energy detector can be implemented by averaging frequency bins of a Fast Fourier Transform (FFT), as outlined in Figure 9 [24]. Processing gain is proportional to FFT size N andobservation/averaging time T. if value of N increases frequency resolution improves which help in reliable Narrow Band (NB) signal detection.Also, greater averaging time decreases the noise power thus improves SNR. However, due to non-coherent detection method used for processing,$O(1/SNR^2)$samples are required to meet a probability of detection constraint [13].

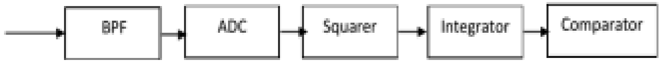

Figure 9: Implementation of energy detector

Advantage of Energy Detection

- Easy to implement.
- Low computation complexities.
- Need to estimate only noise power to set threshold.
- Detection is independent of transmission from PU.

Disadvantage of Energy Detection

- Based upon assumptions i.e. static environment scenario.
- Uncertainty in threshold setting.
- Highly susceptibility to uncertain noise.
- Doesn't make differentiation between modulated signal, noise and interferences.
- Asrecognition the interference not possible in ED, soit cannot be benefited from adaptive signal processing for canceling the interferer.
- Spread spectrum signals detection is not possible in ED.

Matched filter Detection

Matched filter detection is an optimal approach as it maximizes the output SNR. The output of MF is compared with a threshold to decide about the presence or absence of PU signal.
It require prior knowledge (such as modulation type and order, pulse shaping, packet format) of PU signal for effective demodulation of PU signal. To storesuch information CR memory is required, but the bulky part is that for demodulation it has to achieve coherency with primary user signal by performing timingsynchronization, carriersynchronization and channel equalization.

Advantage of Matched filter Detection

- Optimal method i.e. maximize SNR.

Disadvantage of Matched filter Detection

- Dedicated receiver is required for every PU.
- Synchronization circuitry required.

Cyclostationary feature detection

This method focus on finding out specific feature i.e. signature of PU. Generally signals to be transmitted are coupled with sine wave carriers, pulse trains, repeating spreading and hoping sequences, or cyclic prefixes which result in built-in periodicity i.e. make signal cyclostationary. This cyclostatinay nature is result of modulation, but in some case it is intentionally introduced for channel estimation and synchronization (via pilot signals) Even though the data is a stationary random process, hence the signal to be transmitted comes out to be cyclostationary. This can then be used for detection of a random signal with a particular modulation type in a background of noise and other modulated signals [25-31].
Implementation
Cyclostationary feature are mathematically represented in the form of Spectrum Correlation Function (SCF) which is given as

$$S(f)=\lim_{T\to\infty}\lim_{\Delta t\to\infty}\frac{1}{\Delta t}\int_{\frac{-\Delta t}{2}}^{\frac{+\Delta t}{2}}\frac{1}{T}X_T(t, f+\alpha/2)X^{*}_T(t, f-\alpha/2)dt$$

Implementation of SCF for cyclostationary feature detection is illustrate in Figure 12

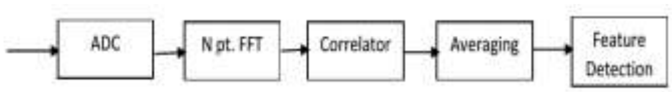

Figure 10: Implementation of cyclostationary detector

Advantage of Cyclostationary feature detection

- Ability to differentiate between types of signals i.e. PU from noise and interference.
- Ability to differentiate even between PU signals from different transmitter.
- Reliable and robust detection in noise uncertainty.

- Hidden terminal problem likely to occur less.
- Good performance in low SNR.

Disadvantage of Cyclostationary feature detection

- Increased computational complexities.
- Large sensing time.

Cooperative sensing

Concept of cooperative sensing comes from the limitation of non-cooperative detection approach is its degraded performance in the presence of multi-path fading and shadowing. For example Digital TV measurements report show standard deviations of 2.0 to 4.0 has been noticed in case of lognormal shadowing effects [32]. This problem can be solved by take advantage of the spatial diversity i.e. using more than one CR receiver. Ifsome SUs are in deep fade or observe severe shadowing, asshown in Fig. 11, there might be other SUs, in the network,with relatively strong signal from primary transmitter.Combining the sensing information from different CRs gives a more reliable and improved spectrum awareness. There are basically few points regarding to cooperative sensing

- What are the benefit from cooperation?
- How cooperation among CR occurs i.e. how cognitive radios cooperate?
- What is the overhead linked with cooperation?
- Who perform sensing?
- Who take final decision about spectrum opportunity?

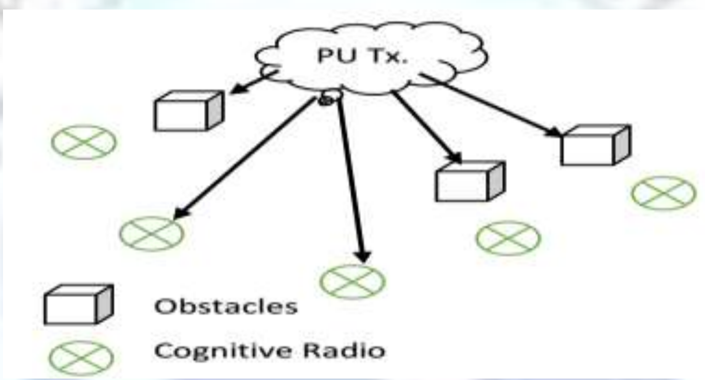

Figure 11: Cooperative SS in a shadowed environment

Based on discussion so far cooperative sensing can be classified into two broad groups. One Based upon how decision are made in two classes centralized and distributed sensing, and second based upon how information being shared in two classes single hop and multi hop.
Almost every Cooperative Spectrum Sensing (CSS) is composed of series of actions involving Local Sensing, Reporting and Information Fusion [33].

Centralized and distributed cooperative sensing

In centralized cooperation, a central unit, also called the fusion center (FC), decides about the absence or presence of primary transmission after collecting local sensing information from cooperating SUs [34, 35].This spectrum hole informationis then either broadcast to all CRs or central unit or FC itself controls the CR traffic by managing the spectrum usage chance in an optimal fashion. Access Point (AP) in a wireless local area network (WLAN), Base Station (BS) in a cellular network and CR in ad hoc networks serve as function of FC. In ad hoc networksany CR can act as a master node to coordinate CSS.

In distributed cooperation, CRs do not rely on a FC to make a cooperative decision. Instead, CRs communicate among themselves and converge to a joint global decision on the presence or absence of PU in an iterative manner [36-38].

This has been carried out in three basic steps defined by a distributed algorithm as follows:

- Each cooperating CR forward its local sensing data to otherCR users in its neighborhood (defined by transmission range of CR user).
- Each cooperating CR combine its sensing information with received data from other users to decide about presence or absence of PU based on its local criterion.
- If spectrum hole is not identified, CRs send their combined sensing information to other secondary users in next iteration. The process continues until the scheme converges and a final unanimous opinion on spectrum availability is achieved.

Working principle of centralized and distributed cooperation is diagrammatically explained in Fig. 12 and 13 respectively. In whole CSS operation there are two type of channel.

- Sensing channel (SC): physical channel between primary Tx. and each cooperating CR.
- Reporting channel (RC): channel among CR for establishing coordination.

According to requirement control channel can be implemented using a dedicated spectrum, an un-licensed band such as ISM or an underlay approach such as ultra-wide band (UWB) [39].

Cooperative sensing using Relay

It is significant to consider that under realistic transmission conditions, both SC and RC are not ideal. Such a scenario is shown in Fig. 15 where some receiver (CR1 and CR2) observe strong SC but weak RC (to FC) due to possible shadowing, multipath effect and other environmental abnormalities. In such situations CR having weak RC, sensing information to FC is transmitted via intermediate CRs, these CRS work as a relay.This scheme is popularly known as Relay-assisted cooperative sensing [40].

Single hop and multi hop

In single hop there is direct one to one link between PU and Su i.e. sensing information are directly available to SU. In multi hop scheme sensing data reaches the intended SU through multiple hops, all the in-betweenCR act as relays.

Advantage of cooperative sensing

- Diminish multipath fading and shadowing.
- Improve sensing performance by improving detection probability and minimizing false alarm and miss detection probability.
- Remove hidden terminal problem.

Disadvantage of cooperative sensing

- Require additional infrastructure
- Increase computational complexity
- Control channel overhead

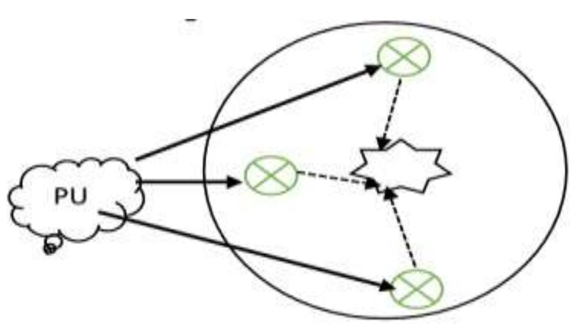

Figure 12: Centralize Cooperative Spectrum Sensing

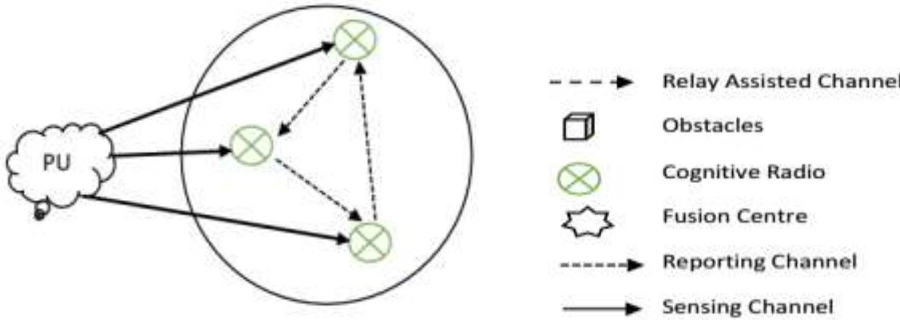

Figure 13: Distributed cooperative SS

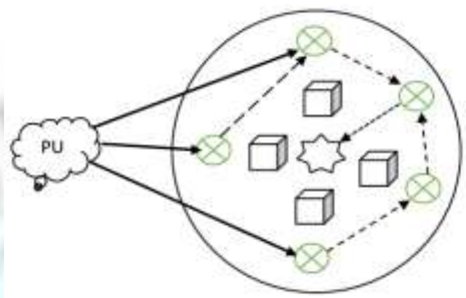

Figure 14: Concept of single hop and multihop SS

IV. MAJOR CHALLENGES IN SPECTRUM OVERLAY SCHEME

In this section major challenges associated with sensing has been described.

Non cooperative sensing

- High detection sensitivity: for detection of low power signal high sensitivity is required. Also In a typical wireless environment, multipath fading and shadowing cause high attenuation of primary transmitted signal like SNR at CR for even high power digital TV signal may be practically as low as −21 dB due to these effects. Moreover it is important to consider in practice, these sensitivity requirements are more demanding and must be raised by additional 30–40 dB [41].
- High degree of flexibility : in dynamic environment parameters are keep on changing, so to cope up with changing dimensions high degree of flexibility required like to adapt with noise/interference power deviations which are dependent on both time and space [42, 43].
- Primary receiver uncertainty and hidden primary terminal problem: as locations of PUs are unknown; the SU may lie outside the PU coverage area or it may be located within the PU's transmission range but primary signal is due to deep fading or shadowing. These practical scenarios are referred to as primary receiver uncertainty problem and hidden primary transmitter problem.
- Sensing based on limited constraints: sensing should be done considering all dimensions to exploit spectrum opportunity efficiently.
- Presence of another secondary network: this effect detection capability in two ways i.e. a secondary signal may be detected as a primary signal or A secondary signal may mask the primary signal thus deteriorating the PU detection capability of CR.

Cooperative sensing

- Control channel overhead: to achieve effective cooperation among CRs channel among them require minimum control overhead. Key challenge is to minimize this overhead by developing some effective strategies.
- Sensing delay: as a result of cooperation, P_d improves but decision time increases as decision is now made by coordination of all CRs. This might cause problem in time critical applications.

- Correlated shadowing: Correlated shadowing degrade performance by increasing probability of miss detection. Also cooperative sensing is most effective when cooperating nodes observer independent fading and shadowing [44, 45]. Hence the effect of correlated shadowing should be minimized.
- Principle of information fusion: information collection become a hectic task when no of nodes in CROWN increases, this in turn require large control channel band width and add computational complexities and sensing delay.
- Mobility of PU and SU (CR): Most of detection algorithm consider static conditions. There may have three more case i.e. PU static CR moving, CR static PU moving and CR and PU both moving. Effect of mobility on detection is reported in [46] although it require further consideration.
- Energy reduction policies: if all CR keep on sensing all times maximum energy consumption occurs. So key challenge in this regard is to let only those CRs sense and report (i.e. consume energy) whotake part in finaldecision. For this, a combination of censoring and sleeping policies is proposed for the cases of known and unknown PU activity in [47].
- Malicious SU: these are unwanted SU, these may intestinally corrupt the sensing information and also may send unrealizable information to FC. To address this problem authentication polices for all user has introduced in [48].

V. FUTURE SCOPE

Immense research has been noticed in CR since FCC allowed secondary access to TV band in Nov 2008. Though there are number of concern to make technology implementable in near future have been introduced below:

- Wide band sensing (near far problem): in WBSS sub-optimal Nyquist rate sampling is used in which a week PU signal near a strong SU may not be properly reconstructed for detection. This cause near far problem.
- Constraints of sensing matrix: sensing matrix used for detection comes from a simple binary hypothesis, but this is not the practical case. A multidimensional matrix must be defined to include all parameters.
- Frequency selective fading: simulation result under frequency selective fading [49, 50] shows limited scope of detection.
- Condition dependency in performance: signal specific approach [49] used in sensing give good result under assumed conditions but fails to detect when scanned frequency band is occupied by some other CR user.
- Continuous changing physical conditions: the physical environment condition keep on changing every time, this effect performance adversely.
- Sensing period and sensing frequency: this is also very important point require consideration that what must be the optimal period for which CR sense and what must be the time after which sensing is done again. This ensure reliability of sensing operation.
- Spread spectrum primary signal detection: SS require some prior knowledge for detection of PU transmission when spread spectrum signaling is employed.There is a single band in the case of direct sequence spread spectrum (DSSS) and multiple bands for frequency hopping spread spectrum (FHSS). In both cases priori information regarding frequency hopping patterns and synchronization pulses can't be obtained to successfully detect primary transmissions [51].

VI. CONCLUSION

CR technology is a paradigm to fulfill insatiable demand in fixed frequency spectrum. Various aspects of CR technology such as cognitive capability, reconfigurability and SS etc. are highlighted in this paper and SS comes out to be most important building block in implementation of CR technology in real time radio environment. Various SS techniques are examined in this paper based upon various dimensions. Implementation issueslike computational complexities, feasibility etc. of SS techniques of studied to get close to the reality. Shortcomings such as dynamic environment, wide band sensing, spread spectrum signal detection, SS constraints, frequency selective fading etc. are explored to find out key problems with SS and these key problems are projected to provide future research directions.

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