White-Space Revolution using Cognitive Radio: Challenges, Opportunities and Comparative Statements on Spectrum Sensing Techniques

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***Abstract*—**Cognitive Radio (CR) technology has a capacity to dynamically utilize the unused spectrum i.e. white spaces, because of the advances in electronics and government policies. This article discusses the challenges and opportunities of this technology in agriculture area of remote location. Also the comparative study of sensing schemes is reviewed

***Keywords*—**Cognitive Radio Network,Spectrum Sensing

I. Introduction

The various wireless technologies are currently available for last-mile broadband access including cellular systems, WiMAX and Wi-Fi. But technical aspects such as coverage and capacity, installation and operational cost and business models must be considered for a successful development of wireless broadband in rural communities and emerging markets [1].

Especially in the agricultural part of the rural area, only wireless option of the broadband is viable because of the vast agricultural land. Many technologies have been suggested and implemented based on broadband in rural area [5] [6] [7]. But broadband is not always feasible and available in remote part of any country because of the proprietary nature and other problems in rural area

Recent advances in cognitive Radio (CR) [3] [4] have enabled the development of advanced wireless system that can use the radio spectrum more efficiently. In particular, wireless Regional area Networks (WRANS) standards IEEE 802.22 [8] is being currently developed based on this cognitive radio technology, where opportunistically access of spectrum is assumed to be granted for secondary user.

II. CR BASED WRAN: CHALLENGES

A review of published research in the policy and technology of this broad area of cognitive Radio based wireless networks indicates that the community is addressing the challenges from multitude of angles. In this paper we only consider the cognitive Radio based Wireless Regional Area Network (WRAN) use full for agriculture and rural area. Also the shared use of Exclusive Licensed spectrum [SUELS] model [1] is considered for WRAN challenges.

SUELS model is first to explore simultaneous shared use of spectrum wherein there is a primary licensed owner of spectrum band and multiple secondary users opportunistically share the band. This model of access classified in to two types: spectrum underlay and spectrum overlay. The challenges in both types are describe here.

A. Spectrum Underlay Network Challenges

In spectrum underlay approach the secondary users limit their transmit power to very low levels such that their signal do not interfere with primary user. Because of this restriction the range of communication is short. Still it is useful in high density area for personal communication this network is not suitable for WRAN application.

Because of its conservative nature it is not suitable for most aggressive spectrum use as it is limits the type of network configuration. Ultra Wide Band (UWB) technology represents one such spectrum underlay technology [9]. Here the transmission of the secondary users is spread over a very wide spectrum band using low power short length pulses. The FCC imposed requirement that transmission be over a size greater than 500 MHz and with a power limit of – 41.3 dBm/MHz which translated to 75 Nanowatts/MHz, makes the radiation of UWB devices comparable to such as computer monitors and TVs classified as unintentional radiators. Some type of modulation used for data transfer in a UWB system lead to spectral lines in the power spectral density of UWB signals and thus cause interference to licensed system and also make UWB more susceptible to primary signal.

B. Spectrum Overlay Network Challenges

The spectrum overlay model utilized more cognitive radio properties and more attractive for new cognitive radio network (CRNs). As it enables devices to operate in the spectrum white spaces or spectrum "gaps" in the spatio- temporal domain. The following are the three fundamental cognitive tasks described in [4].

a) Radio scene analysis
b) Channel state estimation and predictive modeling.
c) Transmit power control and dynamic spectrum management.

CRNs can use cooperative spectrum sensing (SS) or non cooperative spectrum sensing method.In co-operative SS, combining the sensing information from different cognitive radio gives a more reliable spectrum awareness. In the presence of multipath fading and shadowing, cooperative SS method help to detects the spectrum but increases the complexity, cost and power consumption of the network. In the rural area the problem of multipath fading and shadowing is less because of small houses and plane territory. So to reduce the complexity of network, we suggest the non-cooperative spectrum sensing technique.

Following are the challenges of non- cooperative spectrum overlay networks, based on the above mentioned three fundamental tasks of CRNs.

1. *Challenges in Radio scene analysis of non-cooperative CRNs.*

Cognitive Radio needs to sense their multidimensional radio environment. It has no information regarding the primary communication over licensed band. This makes Spectrum sensing a very challenging task. Poor CR sensitivity in noisy atmosphere results in missed detection of primary user (PU), ending in secondary transmission offering unacceptable interference to PU receiver.

Vulnerability of primary receiver to secondary transmission is also high in primary receiver uncertainty problem and hidden primary transmitter problem [10]. In both cases, primary receiver may become vulnerable to harmful interference by secondary communications as such situation make cognitive radio incapable of picking up ongoing primary transmissions.

In multiuser environment, the presence of secondary network affects the detection capability of a CR in two ways. Firstly, a secondary signal may be detected as a primary signal and secondly, a secondary signal may mask the primary signal thus deteriorating the PU detection capability of CR.

2. *Challenges in channel-state Estimation.*

In every communication link, computation of the channel capacity requires knowledge of channel-state information (CSI). This computation requires the use of procedure for estimating the state of the channel. To deal with the channel –state estimation problem, differential detection and pilot transmission [11] are suggested. Channel-state estimation is needed by the receiver for coherent detection of the transmitted signal. It is also needed for calculation of the channel capacity required by the transmitter for transmit-power control.

3. Challenges in transmit-power control and dynamic spectrum management

In cognitive radio based WRAN, the problem of transmit power control is not a major problem because of its infrastructure based nature and its build around the base station. But when CRNs operates in a decentralized manner, the co-operative mechanisms must be exercised to achieve the power control.

Spectrum manager (SM) is a part of the MAC layer management entity (MLME) at the BS and responsible for key decisions and triggering the proper events to ensure protection of incumbents and efficient spectrum utilization while complying with regulatory policies. The SM maintains spectrum availability information, channel classification and selection function, trigger frequency agility related function and manage mechanisms for self-coexistence. Its main challenge is to centralize all the decisions with in the WRAN cell with respect to spectrum availability and utilization. As it is the central intelligence of the system the co-ordination between SM and its counterpart spectrum Automation (SA) at the receiver side is important.SM functions are challenging as listed below [12]

a) Direct a single CPE or a group of CPEs to a different operating channel.
b) Switch the entire cell to a new operating channel.
c) Inform customer premises equipment (CPEs) of channels status updates.
d) Terminate operation in a given channel for a single CPE, a group of CPEs or the entire cell.

III. CRNs IN AGRICULTURE AND RURAL AREA.

The use of cognitive radio technology for extending broadband access to rural and tribal regions was considered an important benefit of a research progress on cognitive radio network [13]. Research is required to support policies, which will not change without substantial demonstration of the value and impact of CRN technologies. CRN research and development requires a multi- disciplinary approach involving researchers in the areas of spectrum policy, economics and social sciences along with technical topics. By deploying smart mesh CRN systems, the network could create the backhaul necessary to reach remote rural area.

Many experiments have been done on test bed deployment in educational project [13]. It also encourages participation and interest of local youth in the fields of technology. Apart from commercial uses of CRNs, it will be very important technology to boost the total GDP of agriculture based economy. Context-aware based solution on agricultural problems have been explained in [5], [6], [14], considering the broad band availability in the rural/agricultural land. CRNs are the best solution in this regard and act as a catalyst in rural economies.

Also it will be very useful in the field of education and health care along with e-governance in rural area. This technology will help to reduce the "digital–divide" problems of the developing world and helps more than 50% population in developing country like India. It will help to take the advantage of information and telecommunication [ITC] wave which is considered to be third wave in human history which impacts most on human society followed after agriculture and industrialization wave.

IV. COMPARATIVE STATEMENTS.

Spectrum sensing is the task of obtaining spectrum occupancy information. To obtain these occupancy knowledge three main approaches can be adopted [10].

1. Spectrum sensing using geo-location and database

2. Spectrum sensing by listening to cognitive pilot channel or PU beacons.
3. Local Spectrum sensing at CR.

The most efficient and simple approach to identity spectrum opportunity with low infrastructure requirement is to detect primary receiver within operative range of CR [10]. As CR cannot locate PU receiver and hence, spectrum sensing techniques usually rely on primary transmitter detection.

Typically, Spectrum sensing is classified into three main detection approaches, viz non-cooperative primary transmitter detection approach, co-operative detection, and detection approach based on spectrum underlay.

In this section we are only discussing non-cooperative primary transmitter detection approach which is useful for WRAN where CR makes a decision about the presence or absence of PU on its local observation of primary transmitter signal.

To find spectrum opportunity, CR may adopt either an on-demand (reactive) or periodic (proactive) sensing strategy. Either of the two approaches may be employed in the presence or absence of cooperation among CRs.

In another category of SS, there are three types, viz, non-blind, semi-blind and total blind. Non-blind schemes require primary signal parameters as well as noise power estimation to reliably detect PU. Semi-blind schemes need only noise variance estimate, whereas most practical sensing techniques are total blind, which required no information on source or noise power to determine PU.

Basic to all these classifications is to detect presence or absence of PU signal. Here, we consider only transmitter detection sensing based on non-cooperative approach which is useful for CR based WRAN. Fig 1. Illustrates the SS classification where different borders are used to group representative transmitter detection techniques as non-blind, semi-blind and blind schemes [10].

Conventionally, the performance of detection algorithm is measured by probability of detection (Pd) and probability of false alarm (Pf). Pd is the probability of correctly detecting the PU and Pm is complement of Pd. Pm indicates the likelihood of not detection the primary transmission when PU is active in the band of interest. Without going into the mathematical details of sensing methods, the following subsections provide a brief overview and comparative statements.

A. Energy Detection (ED)

This method is suitable for wideband SS where CR cannot gather sufficient information about the PU signal. It is simple and also called radiometry. Here received primary signal is filtered with band pass filter to select the desired frequency band. This filtered signal is then squared and integrated over length T. This gives an estimated energy content of signal, which is then compared with threshold value to decide about the presence of PU signal [10]. If Γ represents the energy content of the received signal, and Vt is threshold voltage in signal detection, then comparison of both decides the presence or absence of PU signal. If the selected Vt is too low, the false alarm probability, Pf increases which results in low spectrum utilization. On the other hand, if Vt is kept unnecessarily high, the probability of missed detection Pm will be increased. ED Techniques needs to estimate only the noise power to set its threshold and does not require any information on primary transmission characteristics make its semi blind techniques.

The limitation of ED is addressed in [15]. Here the key limitation is uncertainty in threshold that produces optimum sensing results. Despite the infinite sensing duration ED have limited reliability as energy observations are unable to differentiate between primary and secondary user signals. Other limitation included its poor performance under deep signal fades and inability to detect spread spectrum signal. Because of these factors ED is less robust and less reliable.

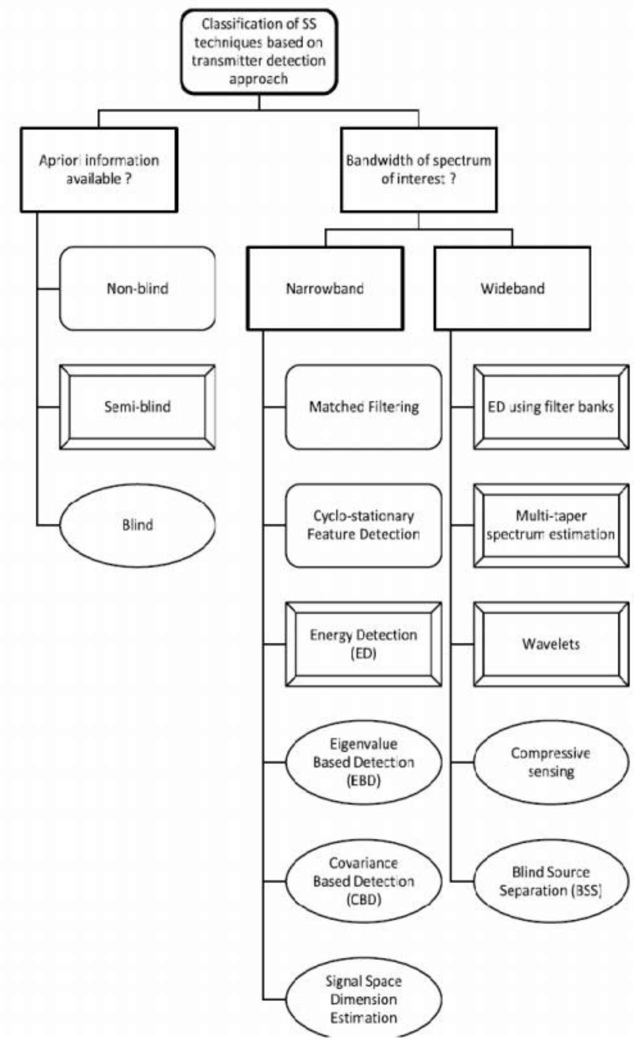

Fig.1 Spectrum Sensing Techniques based on Primary transmission detection [10]

B. Feature Detection (FD)

Digitally modulated wireless signals are in general coupled with pulse trains, sine wave carriers, repeating spreading or hopping sequences. Which induces periodicity in the signal. These cyclo-stationary feature detection extracted RF carriers, symbol rate and modulation type etc. [16]. The favorable aspects of FD are its ability to differentiate signals from interferences and noise and even distinguish among different types of PUs. In a low SNR regime FD outperform ED. But its complexity in the terms of high processing requirements results in large sensing time.

Combination of ED and FD [17] benefits from complementary advantages of both the schemes by doing course detection using ED and then made more reliable by feature detection employing cyclo-stationary detection (FD).

C. Coherent sensing

The known pattern like pilot signals transmitted periodically by PU uses to detected PU coherently. There are two main approaches of coherent sensing: Correlation detection (waveform based) and match filtering.

1. Correlation detection

It consists of correlator which exploits the known patterns in PU signal by correlating the received primary signal with its own copy. Correlated output is then compared with threshold to pick out spectrum hole [18].

2. Matched filtering

It is more complex than correlation detection. Here the output of MF is compared with threshold to decide about the presence or absence of PU signal. It is an optimal detection approach as it maximizes the output SNR. More details can be found in [19].

3. Favorable aspects and limitation

High processing gain achieved in comparatively very short time because of coherent detection [20] is the main advantage of pilot based detection. It also exploits a priori knowledge about PU signals and able to distinguish them from interference and noise. It is also computationally less complex as compared to cyclo-stationary detection (FD).

This spectrum sensing requires CR to demodulate the signal prior to detection. It's also required perfect knowledge of PU transmission parameters like bandwidth, carrier frequency, modulation type and order pulse shaping, frame format etc.
Because of inaccurate information and synchronization errors this non-blind scheme degrades its performance. Its sensitivity to synchronization errors [18] in wave form based sensing and stringent requirement in MF are the limitations in the SS technique.

D. Covariance based detection (CBD)

This method uses the correlation in received signal samples resulting from the time dispersion property of wireless channel and oversampling of received signals [21]. It is also suitable for multi antenna system because received signal samples are also spatially correlated as they originated from the same source signals. In multi-antenna system, multiple copies of received signal can be coherently combined to increase the SNR of received signal. Covariance based detection generally does not require any information about the primary signal. It does not need noise power estimation also, as the threshold is related to Pf and sample size N of the received signal there by, it achieves better performance for highly correlated signals. If the primary signal tends to be uncorrelated then the performance gets degrade.

E. Blind source separation (BSS)

This technique is discussed in [22] for CR model of multiple antennas. It simultaneously detects active PUs in the scanned spectrum. In [23], the performance of this technique in cognitive radio oriented wireless network (CROWN) is evaluated using four channels PU signal using four antennas. In this set up, channel one and two are occupied by pure tones of 5 Hz and 20 Hz, respectively. Channel 3 is amplitude modulated (AM) with carrier centered at 50 Hz while channel four is kept idle and hence contains only noise.

F. Comparison of sensing methods

Fig. 2 shows the comparison between different SS methods in terms of their implementation, computational complexities and sensing accuracies. The selection of method comes with tradeoff between complexity and accuracy. Practically the number of factors significantly compromises the promised sensing accuracy reliability of these schemes.

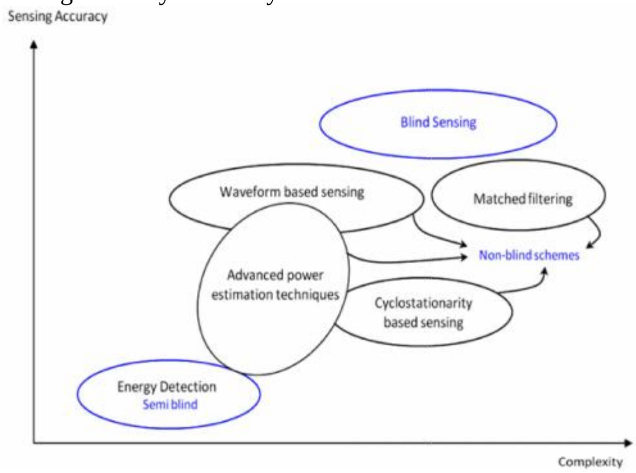

Fig.2 Comparison of SS Methods

ED happens to be most simple but fails in the presence of fading and noise uncertainties. Processing of know information achieves reliability at the cost of complexities. Cyclo-stationary detector is suitable where cyclic frequencies associated with PU are known. Coherent detector is preferred choice where pilot transmission of PU is known. Depending on sensing algorithm used, blind sensing techniques based on received signal covariance matrix and other approaches achieve high accuracy.

V. CONCLUSION

In this paper, we have discussed the challenges in CR based WRAN for agriculture and rural area along with the opportunities in these sectors. We also discussed the various aspects of cognitive radio. Varity of SS techniques along with comparison are presented.

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