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Spectrum Sensing Aspects In Cognitive Radio Networks

(A Novel Technology of Future)

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***Abstract*—Spectrum is a very valuable resource in wireless communication systems, and it is focal point for research and development effortsover the last several decades.The Cognitive Radio network, which is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage, has become an exciting and promising concept. It works on principle of dynamic spectrum management, that helps secondary user to use opportunistically the licensed spectrum belonging to primary user. To implement it ,detecting the absence of primary signal which is technically called detecting a spectrum hole is needed . Sensing the available spectrum opportunities implies estimation of spectrum usage in time, frequency, space, angle, and code; identifying opportunities in these dimensions; and developing effective algorithms for prediction into the future using past information .In this paper, the spectrum opportunity and spectrum sensing concepts are studied and various sensing protocols have also been reviewed**

Keywords—component; PUs,SUs, Wavelet transform, Spectrum hole ,FBSE,MTSE etc.

I. INTRODUCTION

Due to ever increasing wireless networks, the scientific, industrial, and medical (ISM) band has become heavily congested. While the spectrum allocated to licensed users is often used intermittently, CR technology has emerged as a potential solution to overcome scarcity in underutilized frequencies by opportunistic use of the available spectrum. It comprises of primary users called as (PUs) and secondary users as (SUs). The PUs are users licensed to operate in a specific frequency range and have higher priority or legacy rights on the usage of a specific part of the spectrum.; SUs are nodes with cognitive capabilities. SUs basic functionalities includes PU detection, and spectrum-sensing, spectrum-mobility, spectrum-decision, and spectrum-sharing. During a sensing cycle, SU first senses for available spectrum .If PU activity found then an SU will either have to share the spectrum with the PUs without causing interference, or execute a spectrum hand-off, switching to another available channel. Spectrum sensing and transmission times are crucial to maximize the throughput of the SU and are mutually exclusive. Too frequent sensing results in less data transmission by SUs affecting their throughput whereas Infrequent sensing by SUs leads to PU misdetection, causing SUs to interfere with PUs.Spectrum sensing becomes complicated due to many factors like as low signal-to-noise ratio (SNR), little knowledge of PU, fading and shadowing. Therefore Spectrum management plays a crucial role in CRNs. In this paper, we use the definition adopted by Federal Communications Commission (FCC): “Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as mitigate interference, maximize throughput,reduce delay, facilitate interoperability and access secondary markets.” The goal is to point out several aspects of spectrum sensing that are discussed in the rest of this paper. We start by introducing literature review of spectrum sensing concept in Section II describes the related work in the field of Cognitive radio networks .In Section III. cover the challenges and issues in CRN associated with spectrum sensing, while Section IV covers the basic concepts . The various Spectrum Sensing Methods For Cognitive Radio are introduced in Section V. Statistical
modeling of network traffic and utilization of these models for prediction of primary user behavior is studied in Section VI. Finally, sensing features of some modern wireless standards are explained in Section VII and our conclusions are presented in Section VIII.

II. RELATED WORK

The authors in [1] have investigated the design of the sensing time to minimize the SU transmission delay under the condition of sufficient protection to PUs. They have successfully proved that there indeed exists one optimal sensing time which yields the minimum transmission delay and have proposed a novel multi-slot CSS framework. In [2] the authors have presented a low-power, wideband CMOS receiver for spectrum-sensing cognitive radio sensor networks. The low-IF receiver equipped with an inverter based LNA-balun and I/Q sub-threshold rectifier enables low-power and high-speed spectrum sensing. The analysis of the spectrum utilization efficiency in a cognitive radio network based on the frame structure is considered in [3] .It consists of sensing and data transmission slots. The achievable spectrum utilization efficiency of the licensed frequency band has been analytically expressed with energy detection spectrum sensing. The maximum spectrum utilization efficiency is evaluated numerically using optimal sensing and data transmission length. The problem of sensing period optimization in CR Networks is elaborated [4] .Based on a continuous-time Markov chain model, they have proposed an application-specific spectrum sensing method that obtains the sensing period according to the properties of both primary and SUs (hybrid scheme). Interference ratio and the undetected opportunity ratio have been analytically derived using a probability tree-diagram. Using a non-hybrid approach the same parameters derived and first was found to be better performing . The authors in [5] evaluates the performance of individual and cooperative spectrum sensing techniques. The performance of cooperative spectrum sensing was evaluated for different number of users in a cluster and it outperforms the individual spectrum sensing for a particular SNR value. As expected increase in the number of CR users in cluster increases, the performance of cooperative spectrum sensing but at the same time sensing time increases.The spectrum handoffs strategy for SUs in CR-IWSNs where SUs opportunistically use licensed channels as long as its transmission does not interference with PRs has been proposed in [6]. This scheme avoids collision among SUs in a multi-users spectrum handoffs scenario while providing with continuous connectivity between the CR users under dynamic PU activity. This proposed scheme can also achieve significant performance improvement in terms of shorter switching-handoff latency, higher throughput, and reduced the number of spectrum handoff.In [7] the authors have proposed and analyzed reactive control methods for spectrum coordination. Using NS2 Dynamic Frequency Selection (DFS), Power Control (PC) and Time Agility (TA) were evaluated in various network scenarios. The goal is to reduce interference and use spectrum more efficiently by efficiently sharing limited radio resources such as power (space),frequency and time.CAAC algorithm for dynamic channel allocation is based on the task allocation model in ant colony as proposed in [8]. CAAC not only can minimize the cognitive users' handoff rate but also can reduce the handoff latency.CAAC algorithm fits various services of primary users and can be applied in different cognitive radio systems.In [9], spectrum sensing in CR system was discussed. Various physical layer techniques available in the literature were catalogued and evaluated. While selecting the right spectrum sensing technique for CR, speed and accuracy of estimation are the two main metrics. But it was seen that, it is not possible to simultaneously have the best frequency and time resolutions.

III. CHALLENGES IN CRN

This section covers the challenges associated with the spectrum sensing for cognitive radio.

A. Hardware Requirements:

Spectrum sensing in CRN applications requires high resolution analog to digital converters (ADCs) with large dynamic range, high sampling rate and high speed signal processors .To utilise the spectrum effectively the cognitive radio terminals process transmission over a much wider band. Hence for identifying spectrum opportunities, cognitive radio should have the ability to capture and analyze a relatively larger band with additional requirements on the radio frequencies (RF) components such as antennas and power amplifiers. High speed processing units (DSPs or FPGAs) are needed to perform signal processing tasks computationally with relatively low delay.

B. Hidden Primary User Problem:

The hidden primary user problem in Carrier Sense Multiple Accessing (CSMA) is also applicable to CRN networks. The factors including severe multipath fading or shadowing observed by secondary users while scanning for primary users' transmissions mainly cause Hidden terminal problem. The primary transmitter's signal cannot be detected because of the locations of devices thereby causing unwanted interference to the primary user (receiver). Cooperative sensing is implemetable for handling hidden primary user problem

C. Detecting Primary Users using Spread Spectrum:

In commercial devices two main technologies operate: fixed frequency and spread spectrum. . Fixed frequency devices operate at a single frequency or channel eg. IEEE 802.11a/g based WLAN. While in spread spectrum technologies used are frequency hopping spread-spectrum (FHSS) and direct-sequence spread spectrum (DSSS). FHSS devices hopping is performed according to a sequence that is known by both transmitter and receiver and operational frequencies changes dynamically to multiple narrowband channels. DSSS however use a single band to spread their energy. Primary users using spread spectrum signalling are difficult to detect as the power of the primary user is distributed over a wide frequency range . This problem can be partially avoided if the hopping pattern is known and perfect synchronization to the signal can be achieved.

D. Sensing Frequency and Duration:

The major challenge for cognitive radio design is to identify the presence of primary users within certain duration as they can claim their frequency bands anytime while cognitive radio i.e SUs is operating on their bands. Therefore to prevent interference to and from primary license owners, sensing methods should be able able to identify the presence of primary users as quickly as possible and should vacate the band immediately. With the goal is to maximize the average throughput of secondary users while protecting primary, selection of sensing parameters like the speed (sensing time) and reliability of sensing are crucial. Sensing frequency, i.e. how frequently spectrum sensing should be performed needs to be chosen carefully. If primary users are known to change slowly, sensing frequency requirements can be relaxed. A good example for such a scenario is the detection of TV channels .In addition to sensing frequency, channel move time , channel detection time, and other timing related parameters also needs to be defined. In public safety bands, sensing should be done as frequently as possible in order to prevent any interference.Optimum sensing durations for available channel search and monitoring used channel are to be handled efficiently.

E. Decision Fusion in Cooperative Sensing

The sharing of information among cognitive radios and combining results of various measurements is a challenging task. The shared information is nothing but soft or hard decisions made by each cognitive device. The optimum fusion rule as defined by Chair-Varshney combines the sensing information based on log-likelihood ratio test. The credibility of CR depends on their distance from a licensed user and the channel conditions. At the AP ,information fusion is made using the decisions of each cognitive radio and their credibility. And using this information required number of nodes for satisfying a probability of false alarm rate is investigated.

F. Security Issues :

In cognitive radio, to mimic a primary user, a selfish or malicious user can modify its air interface. This can mislead the spectrum sensing performed by legitimate primary users. Such a behavior or attack is investigated in and is called as primary user emulation (PUE) attack.

IV. BASIC CONCEPTS USED IN CRN

Cognitive Radio is a novel solution to spectrum scarcity and spectrum under-utilization. They are envisioned as reconfi-gurable devices capable of sensing their environment and accordingly adapting to any changes."A cognitive radio is a radio that can change its transmitter parameters based on interaction with the environment it operates". CR seeks for transmission opportunities in the white spaces called as spectrum holes and choose the optimal available one, for maximizing many functions related to users' such as throughput, fairness, etc., while causing no or minimal interference to PUs.

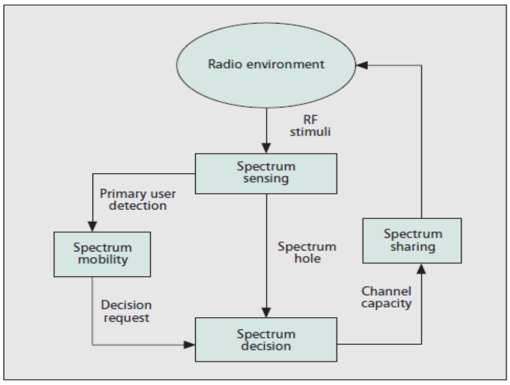

Fig. 1. The cognitive cycle

CRs have two main characteristics

A. Cognitive capability

It is the ability of these devices capable to sense their environment and choose the best available transmission mode (e.g. modulation type). The spectrum management process where several physical layer parameters such as modulation type, power, frequency etc are estimated that makes this feasible. CR performs for adaptive operation, sense its environment and adapt accordingly, is referred to as the cognitive cycle, shown in Fig. 1. SUs access any of the available spectrum holes opportunistically and vacates the specific band immediately if an incumbent signal is detected.

The cognitive cycle consists of the following mechanisms:

Spectrum sensing: Incumbent signals' detection is performed during spectrum sensing that is one of the most important components of a CR. Two time scales are defined: (i) fast sensing (1ms/channel), and (ii) fine sensing that is dynamically determined by theBS. All SUs sense the spectrum and send their observations to the BS that takes the final decision about the incumbent's signal presence or absence. IEEE 802.22 uses the energy detection method for the detection of the incumbent signal because of its simplicity and low computational overhead. CRs are mobile devices with medium or low computational capabilities and with energy constraints. Except "energy detection", several other methods that are proposed are (i) waveform based sensing, (ii) cyclostationarity based sensing, (iii) radio identification based sensing, and (iv) matched filtering

Spectrum analysis is the process of gathering available spectrum holes information (through feedback from spectrum sensing), analyzes several channel parameters and network characteristics (e.g. bit error rate, capacity, delay) for each spectrum hole and then feedback the spectrum decision.

Spectrum decision is the process which selects the most appropriate spectrum hole for transmission which can be performed by a single CR, or output of several cooperating CRs .

B. Reconfigurability :

It enables a CR to adapt to its environment by changing several of parameters like frequency, modulation. The CRs devices are equipped with reprogrammable features (e.g. field programmable gate arrays or general purpose processors) that can change their physical layer parameters on-the-fly.

It involves the change/modification/update of several characteristics of their physical layer parameters such as: (i) type of modulation, (ii) carrier frequency, (iii) transmission power, etc.The physical layer mechanisms purely implemented at the hardware level are not sufficient. SDRs are a viable solution for this concern. These devices have radio functionality modules implemented in software, providing reconfigurability by using the same equipment in different regions and under different policies. It consists of two distinct parts: hardware and software. The software part consists of several sub-modules:

- Radio operation environment (ROE) that contains all the core modules for the radio configuration (e.g. driver, middleware, operating system).
- Radio applications (RA) that controls the functionality of the radio platform, implementing the communication protocols and the air interference.
- Service provider applications (SPA) include services such as messaging, video, voice, etc.
- User applications (UA) include all the applications installed by a user (e.g. text editors, web browsers, etc.).

V. SPECTRUM SENSING METHODS FOR COGNITIVE RADIO

In CR, the secondary users need to scan a large swath of licensed frequency to locate the unoccupied spectrum as quickly and accurately. The following sub sections discuss possible spectrum estimation techniques for CR.These technique cover only sensing the spectrum while no routing capabilities are mentioned

The various aspects related to CRN are as shown in Fig.2.below

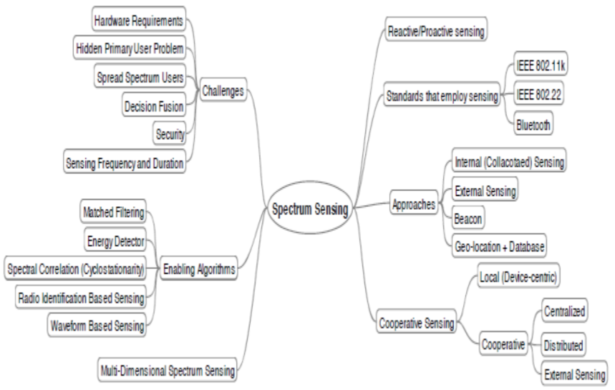

Fig2. CRN : Various aspects

A. Pilot Detection via Match Filter Technique

For pilot detection, Cabric et al in use matched filter. Here the primary user sends pilot signal with data. The pilot signal is to be known by secondary users too that allows them to perform timing and carrier synchronization to achieve coherence . Secondary users should also have full prior knowledge of modulation type, pulse shaping and packet format. In this scenario, secondary users should provide for each primary user class, separate dedicated receiver, which is impractical.

B. Energy Detection

Second approach is Energy Detection, which is a type of non-coherent detection, where prior knowledge of pilot data is not required. It consists of a low pass filter to remove out of band noise and adjacent interference, square law device as well as an analog to digital converter to compute the energy. Such an implementation is not flexible for sine waves and narrowband signals.

C. Cyclostationary Feature Detection

This method has a base on the cyclostationarity of the modulated signal .The transmitted data is generally taken to be a stationary random process. However, when modulated with sinusoid carriers, cyclic prefixes (as in OFDM) and code or hoping sequences (as in CDMA), a cyclostationarity is induced i.e. the mean, autocorrelation and statistics show periodic behavior. This feature is exploited in a detector .It measures a signal property called Spectral Correlation Function (SCF).

D. Multi Taper Spectrum Estimation

The periodogram estimate may be viewed as the output of many filters banks having each point in the power spectrum estimate that corresponds to output of a filter. The filter bank is constructed by modulating a single prototype filter. The Multi Taper Spectrum Estimator as proposed by Thomson, works similar but it uses multiple orthogonal prototype filters to improve the variance of estimated power and reduce the leakage. The process is initiated by collecting the last M received samples in a vector x(n) = [x(n) x(n-1) ….. x(n-M+1)]T .It is represented as a set of orthogonal slepian base vectors.

E. Filter Bank Spectrum Sensing

Farhang-Boroujeny has proposed filter bank spectrum estimation (FBSE) for CR by using a pair of matched root Nyquist-filter. Multicarrier modulation is used as the underlying communication technique here. Every point in power or frequency spectrum is considered as the output of single filter or multiple filters operating at the same band. Hence here, the frequency spectrum is considered as the output of multiple filters.

F. Wavelet Based Edge Detection

Wavelets and wavelet transform are latest additions to communication system tool box .They possess excellent time-frequency localization properties .Using these they can serve as powerful mathematical tools for analyzing local spectral structure to identify singularities and edges. Wavelet based wideband spectrum sensing approach are excellent for dynamic spectrum management. The signal spectrum over a wide frequency band is decomposed into elementary building blocks which are non-overlapping sub-bands and well characterized by local irregularities in frequency. Then the entire wideband is modeled as a sequence of consecutive frequency sub-bands, where the power spectral characteristic is smooth within each sub-band but exhibit a discontinuous change between adjacent sub-bands. Information on the locations and intensities of spectrum holes and occupied bands is derived by considering the irregularities in PSD. The main attraction for wavelets in this application is in their ability to analyze singularities and irregular structures which can be used to characterize the local regularity and edges of signals. Hence, the method is also called Edge detection.

VI. CONCLUSION

This paper considers spectrum sensing as a crucial aspect in CR system was discussed, catalogued and evaluated. Speed and accuracy of estimation are the two main metrics for selecting the right spectrum sensing technique. But to simultaneously have the best frequency and time resolutions is a matter of study as there is a trade-off between the speed (time resolution) and accuracy (frequency resolution) of estimation. Traditional techniques such as periodogram or STFT based estimators cannot be tuned to vary the time-frequency resolutions as they suffer from drawbacks such as leakage and large variance in power spectrum estimates. Other techniques like MTSE and FBSE successfully overcome these infarctions, but they too lack the keys to adjust and optimally tailor the time-frequency resolution window. The theory of wavelets stands out for spectrum estimation applications for it has properties required to dynamically tune the time and frequency resolution by playing with dilated versions of the wavelet and scaling functions. Convolving the wavelet with the power spectrum density of the received signal, taking advantage of the first and second order derivative of this convolution, the location of the frequency boundaries of each band within the wide band of interest can be found. A tradeoff between time-frequency resolutions with minimum complexity offer the best spectrum sensing approach for Cognitive Radio. Future research should focus on finding means to identify the optimal spectrum sensing technique with flexible tuning capability in terms of time and frequency resolution in Adhoc Networks.

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