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Cognitive Radio Spectrum Sensing Methods and Power Detection Estimation

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***Abstract*— With the growing technology, the demand of wireless applications has put many view on the usage of its available radio spectrum which is limited and precious. However, there are many frequencies that are not properly utilized among assigned fixed spectrum. Cognitive Radio technology enables the use of spectrum in dynamic manner. It will enable to obtain the best available spectrum through cognitive capability and re-configurability. In this paper we are going to discuss the behavior of different methods of spectrum sensing, its challenges and energy detection phenomenon.**

***Index Terms*—Primary User, Secondary User, Spectrum Sensing , Energy Detection.**

I. Introduction

Cognitive radio network represent an innovative approach to wireless engineering in which radios are designed with an unprecedented level of intelligence and agility. Cognitive radios are able to monitor, sense, and detect the conditions of their operating environment, and dynamically reconfigure their own characteristics to best match those conditions. Cognitive radio technology enables radio devices to use spectrum (i.e., radio frequencies) in entirely new and sophisticated ways. It works on this dynamic Spectrum Management principle which solves the issue of spectrum under-utilization in wireless communication. In this the unlicensed systems (Secondary users) are allowed to use the unused spectrum of the licensed users (Primary users).
If we scan the portions of radio spectrum, we would find that some frequency bands are largely unoccupied most of the time while some other frequency bands are only partially occupied and the remaining frequency bands are heavily used.

II.SPECTRUM SENSING AND ITS CHALLENGES

Cognitive Radio technology enables the use of spectrum in dynamic manner. A Cognitive Radio can be defined as a radio that can change its transmitter and receiver parameters

based on interaction with environment in which it operates. The main objective of Cognitive Radio is to obtain the best available spectrum through cognitive capability and re-configurability. The Cognitive Radio enables the usage of temporary unused spectrum which is referred to as white spaces as shown in Fig. 1 ,

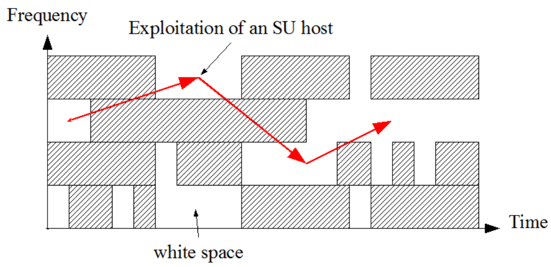

Figure 1: Dynamic access spectrum sensing

A. Spectrum Sensing

Spectrum sensing is based on a well-known technique called signal detection. Signal detection can be described as a method for identifying the presence of a signal in a noisy environment. Analytically, signal detection can be reduced to a simple identification problem, formalized as a hypothesis.

$$H_1 : x(n) = s(n) \cdot h + w(n) \quad (1)$$

$$H_0 : x(n) = w(n). \quad (2)$$

Where, $x(n)$ is the received signal by secondary users, $s(n)$ is the transmitted signal of the primary user, h is the channel coefficient; and $w(n)$ is additive white Gaussian noise with variance σ_w^2.

H_1 and H_0 are the sensing states for absence and presence of signal respectively. We can define four possible cases for the detected signal

1. Declaring H_1 under H_1 hypothesis which leads to Probability of Detection, P_d.
2. Declaring H_0 under H_1 hypothesis which leads to Probability of Missing, P_m.
3. Declaring H_1 under H_0 hypothesis which leads to Probability of False Alarm, P_f.
4. Declaring H_0 under H_0 hypothesis which leads to free band detection.

If H_0 is decided under H_1 hypothesis, then it leads to probability of missing, P_m, that is probability of deciding that there's no primary signal while primary signal actually exists which leads to interference to primary user. If H_1 is decided while H_0 is observed then it refers to find the probability of false alarm which indicates to decide primary signal exists while there's actually no primary user communicating thus leads to inefficient usage of the spectrum.
The major challenge of the cognitive radio is that the secondary user needs to detect the presence of primary user

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and to quickly quit the frequency band if the corresponding primary radio emerges in order to avoid interference to primary users.

B. Classification of Spectrum Sensing Techniques

Depending on the need of spectrum sensing, same can be categorized into two types

1. Spectrum Sensing for Spectrum opportunities

a. Primary transmitter detection

Based on the received signal at CR users the detection of primary users is performed. It is subdivided into following types:

i. Matched Filtering

ii. Energy Detection

iii. Cyclostationary Feature Detection

b. Cooperative and collaborative detection

2. Spectrum Sensing for Interference detection

a. Interference temperature detection

In this approach, CR system works as in the ultra-wide band (UWB) technology where the secondary users coexist with primary users and are allowed to transmit with low power and are restricted by the interference temperature level so as not to cause harmful interference to primary users.

b. Primary receiver detection

In this method, the interference and/or spectrum opportunities are detected based on primary receiver's local oscillator leakage power. This technique of detection depends on the concept of how data transmission starts among primary users.

III. Cyclostationary Feature Detection

A. Cyclostationary spectrum sensing by adding and detecting signature

Cyclostationary signature is a feature, intentionally embedded in the physical properties of a digital communications signal, which may be easily generated, manipulated, detected and analyzed using low complexity transceiver architectures. This feature is present in all transmitted signals, requires little signaling overhead and may be detected using short signal observation times. This signature may be used to uniquely identify a cognitive network and upon detection, facilitates signal acquisition and the establishment of a communications link.

Detection and analysis of Cyclostationary signatures may be achieved using low-complexity receiver architectures and short signal observation durations.

A signal $x(t)$ is defined to be second order Cyclostationary (in the wide sense) if its autocorrelation function,

$$Rx\,(t,\tau) = E\,[x(t+\tau/2)\,x(t-\tau/2)] \qquad (3)$$

is periodic in time t for each time lag τ.

These periodicities are examined using the cyclic autocorrelation function (CAF)[1]

$$R_x^{\alpha}(\tau) = \lim_{\Delta t \to \infty} \frac{1}{\Delta t} \int_{-\Delta t/2}^{\Delta t/2} x\left(t+\frac{\tau}{2}\right).x\left(t-\frac{\tau}{2}\right) e^{-\tau 2\pi\alpha}\, dt \qquad (4)$$

for cyclic frequency α and measurement interval Δt.

Second order Cyclostationary gives rise to specific correlation patterns which occur in the spectrum of the signal. These patterns may be used equivalently to examine the Cyclostationary of the signal and may be analyzed using the spectral correlation function (SCF)[1].

$$\lim_{\Delta t \to \infty} \frac{1}{\Delta t} \int_{-\Delta t/2}^{\Delta t/2} \Delta f X_{1/\Delta f}\left(t, f+\frac{\alpha}{2}\right).\, X_{1}{}^{*}_{/\Delta f}\left(t, f-\frac{\alpha}{2}\right) dt \qquad (5)$$

where,

$$X_{1/\Delta f}\ (t,v) = \int_{t-1/2\Delta f}^{t+1/2\Delta f} x(u) e^{-i2\pi}\, du \qquad (6)$$

represents the complex envelope of the narrow-band-pass component of $x(t)$ with center frequency $v$and bandwidth Δf. Together the CAF and SCF provide a comprehensive means of examining the second-order Cyclostationary of a signal.

a. Signature Generation

For this type of Cyclostationary spectrum sensing scheme cyclic prefix in orthogonal frequency division multiplexing (OFDM) is used and hence signal may be exploited to perform key task of blind channel identification [2].

i. Blind channel identification

In most of the cases of Cyclostationary feature detection only second order Cyclostationary properties are considered. But the Cyclostationary sources used in practical applications are not necessarily zero-mean but may be first-order (FIO) Cyclostationary, which is, in particular, the case for some amplitude modulated (AM) sources[5] and for some nonlinearly modulated digital sources such as frequency shift keying (FSK) sources or some continuous phase frequency shift keying (CPFSK) sources, which belong to the more general family of the so-called continuous phase modulation (CPM) sources[5]. Orthogonal frequency division multiplexing (OFDM) signals may be represented as a composite of N statistically independent subchannel quadrature amplitude modulated (QAM) signals:

$$w(t) = \sum_{k} \sum_{n=0}^{N-1} \gamma_{n,k} e^{j\left(\frac{2\pi}{T_s}\right)nt} q(t-kT) \qquad (7)$$

where$w(t)$ is the complex envelope of an OFDM signal with a cyclic prefix $\gamma_{n,k}$ is an independent and identically distributed (IID) message symbol sequence, $N$is the number of subcarriers and $q(t)$ is a square shaping pulse of duration T. Ts is the source symbol length and $Tg$is the cyclic prefix length such that $T = Ts{+}Tg$.

Due to the statistical independence of the subchannel QAM signals, the problem of cyclostationary analysis of OFDM may be reduced. In the absence of a cyclic prefix, subcarrier orthogonality causes destruction of the individual QAM signal cyclostationarity. However, the use of a cyclic prefix causes a loss of subcarrier orthogonality and permits inherent QAM signal features to be detected. And the spectral

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correlation of the complex envelope $w(t)$ of an OFDM signal can be written as[3]

$$S_w^{\alpha}(f) = \begin{cases} \delta^2 \gamma / T \sum_{n=0}^{N-1} Q\left(f - \frac{n}{T_s} + \frac{\alpha}{2}\right) . Q^*\left(f - \frac{n}{T_s} - \frac{\alpha}{2}\right) . \alpha = \frac{k}{T} \\ 0, \qquad \alpha \neq \frac{k}{T} \end{cases} \quad (8)$$

where,

$$Q(f) = \frac{\sin(\pi f T)}{\pi f} \quad (9)$$

is the Fourier transform of the square shaping pulse $q(t)$.

These inherent features of OFDM signals may be used to perform tasks such as blind channel identification [2] however they are unsuitable for use in the context of cognitive network coordination for dynamic spectrum access. In order to embed unique signatures using cyclostationary features, it must be possible to directly control and manipulate the properties of those features. In the case of these inherent features, this involves altering Tg, the cyclic prefix length. As the cyclic prefix length is a key parameter determining the performance of an OFDM-based system, this may not be possible.

b. Signature Detection

Now the existing OFDM receiver designs typically involve the use of a Fourier transform in order to demodulate a received signal. In designing an estimator based on the use of a Fourier transform it may be possible to incorporate the use of cyclostationary signatures using minor modifications to an existing OFDM receiver design.

c. Frequency-Selective Fading Channels

A limitation of cyclostationary signatures generated using single OFDM subcarrier set mapping is the sensitivity exhibited to frequency-selective fading. A deep fade occurring at the frequency of a mapped set may severely distort the signature and deteriorate detection performance. Robustness is provided in typical OFDM-based systems through the use of a cyclic prefix, however this approach requires close frequency and time synchronization with the signal of interest. In the context of signal detection, this is not possible. The effects of frequency selective fading may be overcome by increasing the frequency diversity of the cyclostationary signature.

Cyclostationary features generated using multiple subcarrier set mappings only occur at a single cyclic frequency due to the use of a constant set separation, p. For this reason, the number of cyclic frequencies which may be used as unique identifiers are not reduced and the use of signatures to identify multiple independent networks is unaffected.

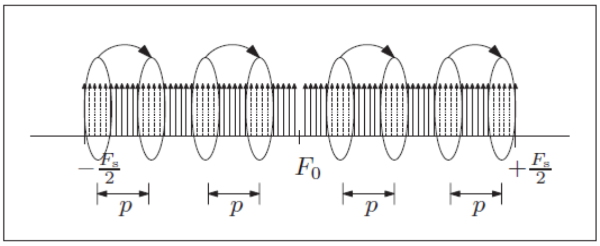

Figure 2: Generation of a Cyclostationary Signature using Multiple OFDM Subcarrier Set Mappings

d. Network Identification

Using OFDM subcarrier-mapping, cyclostationary features may be generated at one of a number of discrete cyclic frequencies. Thus, by embedding a signature with a particular cyclic frequency in a waveform, a transmitting device allows that waveform to be uniquely identified by receiving devices.

e. Frequency Acquisition

After signature detection and network identification, the third key task in cognitive radio is that of frequency acquisition. OFDM systems typically employ a two stage approach to carrier frequency synchronization due to the sensitivity exhibited to adjacent carrier interference. In [4], Schmidl and Cox propose the use of a two-symbol training sequence to facilitate frequency and timing synchronization. The first symbol contains a half symbol repetition and is used for timing synchronization and estimation of the fractional frequency offset. This approach provides an acquisition range of $+/-1$ subcarrier spacing. The second symbol contains a pseudonoise (PN) sequence and is used in conjunction with the first to correct the remaining frequency offset (if any) - an integer multiple of the subcarrier spacing.

IV. RESULTS

Case 1: When all the primary user frequency bands are not occupied and secondary user tries to occupy the free slot.

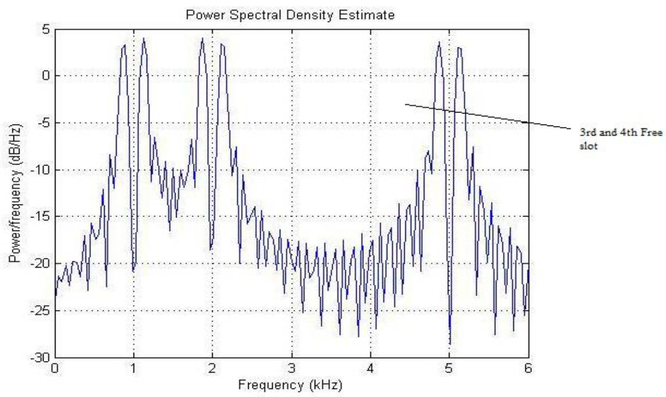

Figure3: All the primary user frequency bands are not occupied

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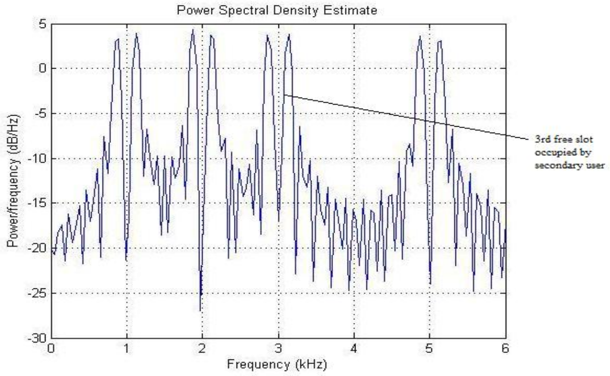

Figure 4: Third free slot occupied by secondary user

Case 2: When all the primary user frequency bands are occupied and secondary user does not find any free slot to occupy.

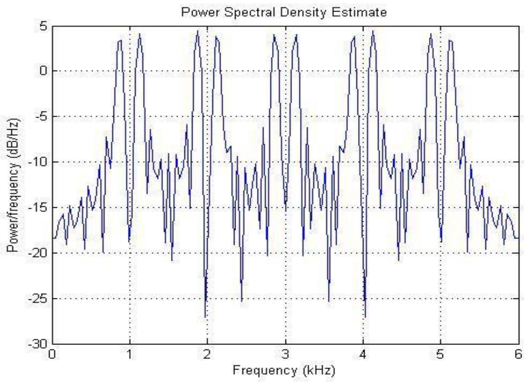

Figure5: All primary user bands are occupied

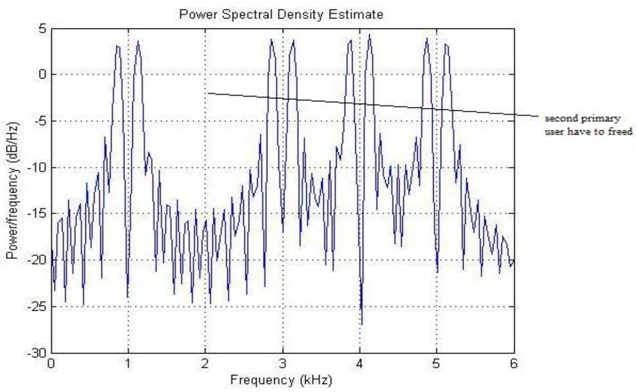

Figure 6: Second primary user slot freed

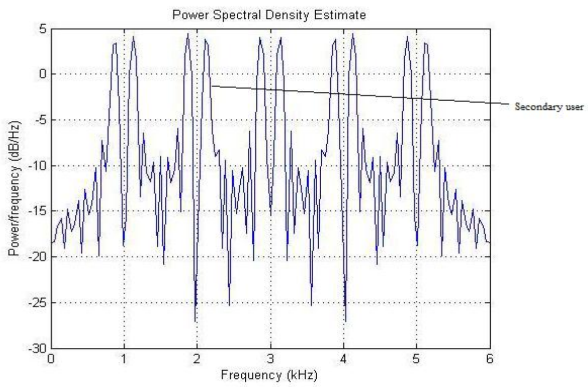

Figure 7: Freed second slot is occupied by secondary user

V. CONCLUSION

The concept of cognitive radio is a promising technique to efficiently use the frequency spectrum.

Spectrum sensing is a crucial task in the cognitive radio system to identify vacant frequency bands to enable opportunistic spectrum access. In particular, reliable detection of the presence of primary users is of uttermost importance since the cognitive radio operating as a secondary system is not allowed to cause harmful interference to the primary user. Thus, the performance evaluation of spectrum sensing schemes is important.

Energy Detection and Cyclostationary Feature Detection method of spectrum sensing for different cases in environment according to number of primary users using the frequency band has been implemented using MATLAB.

Since the different spectrum sensing schemes are associated with different advantages and limitations, a combined detector that consists of an energy detector for coarse sensing of spectrum and a feature detector for more detailed sensing of selected frequency bands could be a useful solution. Also due to the limited awareness of a single cognitive radio node, cooperative sensing will be important in practical cognitive systems.

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