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A Survey of Cognitive Radio's Spectrum Sensing Techniques

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ABSTRACT

Wireless communication (WC), Radio environment (RF) emerges a cognitive radio scheme. It is an intelligent wireless communication system that has more awareness about surrounding environment; depending upon the environment it will give flexible communication as well as effective reuse of the unused available spectrum. Recent Research says 70% of the radio frequency spectrum is not used effectively. Spectrum sensing (SS) is a promising technique to find out the unused portions of the spectrum, called white spaces (WS). There are several algorithms are available to perform this feasibility. In this paper, cognitive radio spectrum sensing methods is presented and explains sensing challenges and reviews various sensing methods. An unlicensed Secondary User (SU) can use the licensed spectrum band without interference to the Primary User (PU). SS is the ultimate task for successful spectrum utilization. It plays a vital function of cognitive radio to avoid the harmful interference with PU's and identify the available spectrum for effective utilization. Finally; Comparative study has been taken out based on the different parameters.

Keywords: Wireless communication (WC); Radio environment (RF); Spectrum sensing (SS); white spaces (WS); Secondary User (SU); Primary User (PU).

1. INTRODUCTION

Spectrum sensing is a technique to develop a wireless communication radio environment. Interference is a issue for different wireless networks are operated in various band levels. Our aim is how to increase the spectrum utilization. To encourage utilization is possible by using Dynamic Spectrum Access technique and it's also a proposed scheme (DSA) [3]. It works at spectrum sharing ideology and it allows unlicensed user can use the white space (WS) or unused licensed spectrum without getting authentication from a licensed primary users (PU). DSA's vital application is cognitive radio (CR). A CR is a smart wireless communication system, can able to acquiring data's from its surrounding environment or depending upon the situation, by operated its autonomously, increase channel reliability and use unused resources dynamically, leads to operate effectively utilize radio spectrum. Cognitive Radio must be adapting various environments and it can able to transmit and receive in various types of bands and to use various modulation identification methods. Spectrum sensing is a one of the promising technique by using CR to identify the unused spectrum [3].

2. COGNITIVE RADIO

Cognitive radio is viewed as a novel approach for improving the utilization of a precious natural resources: the radio electromagnetic spectrum–S. Haykin [19].

The term cognitive radio was introduced by Mitola[20]. Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment, and uses the methodology of

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understanding–by-building to learn from the environment and adopt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters in real-time, with two primary objectives in minds:

1) Highly reliable communications whenever and wherever needed.
2) Efficient utilization of the radio.

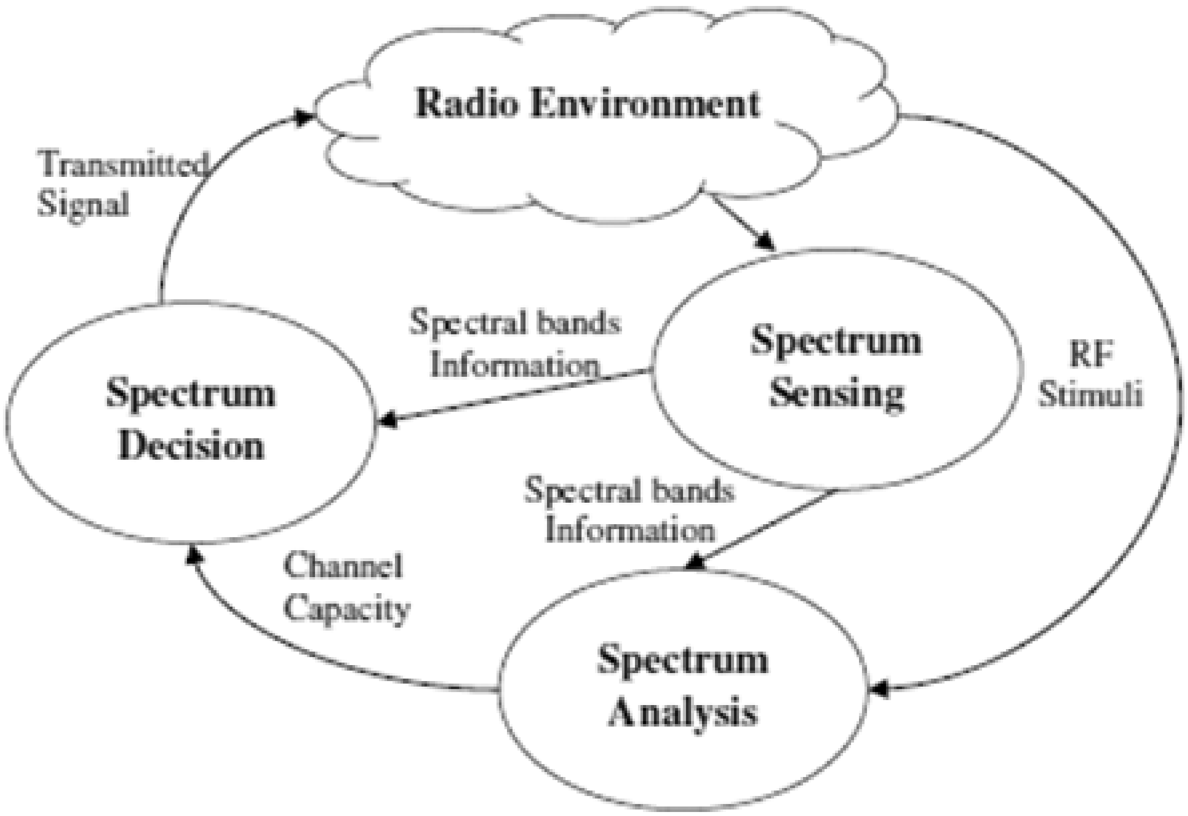

Figure 1: A Basic Cognitive Cycle

To operate the cognitive radio and to interact the surrounding environment [21] in a real time and smartly determine suitable communication parameters based on quality of service (QOS) requirements. A basic cognitive cycle tasks are given above Figure (1).

a) Spectrum sensing: The environment is suitable or not, the cognitive radio should regularly sense the RF environment. If use or increase the spectral efficiency means CR not only to find out the white space and always must be monitoring the whole spectrum.
b) Spectrum analysis: Spectral band characteristics are sensed through spectrum sensing methods and estimated the parameters such as capacity, reliability [21].
c) Spectrum decision: Depending upon the spectrum characteristics a right spectral band will be selected by a CR node. Then the CR chooses new configuration parameters, such as data rate, transmission mode and bandwidth.

3. COGNITIVE RADIO PHYSICAL ARCHITECTURE

CR should be adapting the physical environment and to transmit and receive data's in different bands using various modulations and coding methods in a different radio operating parameters. So hardware does not give such flexibility and the digital signal processing methods are done by using software.

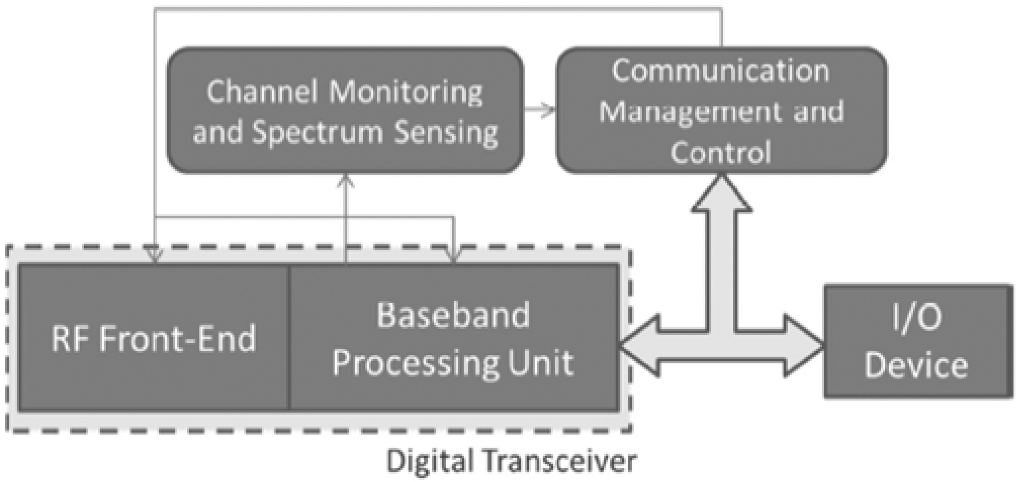

Figure 2: CR Physical Architecture

CR Physical Architecture is shown above in Figure.2 have three sub-systems such as digital transceiver, channel monitoring and spectrum sensing module and communication management and control unit. The digital transceiver subdivided in to the RF front end and the base band processing unit [22]. CR front end is hardware part and its function is to receive the signal, amplify the signal, mixing, filtering and to convert the digital form based upon the signal interest. This cause front end nodes hardware components like antenna, power amplifier and filtering sections. Baseband processing unit consists of software and its response is digital signal processing (DSP), like modulation, coding. It’s all done by field programmable gate array (FPGA), DSP, and General Purpose Processor (GPP). Spectrum sensing part can able to obtaining the data from the radio environment, to identify the unused spectrum by using the identification techniques such as, Energy Detection, Matched filtering etc.., and sending its feedback to the communication management portion. This feedback helps CR to adjust its operation parameters in the RF-front end as well as base band processing unit.SS scanning based on the corresponding values obtained by performance metrics and the switching mode decisions are all controlled by the communication management subsystem in CR [22].

3.1. CR Reconfigurability

Reconfigurability [21] is an important key feature of cognitive radio. CR must change its operational parameters for adapt to RF environment. Operating frequency: CR can able to change its operating frequency while primary user (PU) enters the spectrum. Modulation scheme: According to the user needs and the channel conditions, CR to adapt and reconfigure the modulation scheme. Transmission power: Within the power limit, transmission power can be reconfigured. Communication technology: CR can use different communication systems by changing various modulation schemes.

4. SPECTRUM SENSING

Spectrum sensing aim is to identify the white space, and to watch the primary user (PU) activity. When the primary User reenter the licensed spectrum, the CR immediately free the spectrum without any interference on the PU [5]. Spectrum sensing allows identifying the spectrum holes (SH).

4.1. Hypotheses Testing

Two hypotheses are helped to solve a signal detection problem.

$$\left.\begin{array}{l} H_0\text{: Primary user absent.} \\ H_1\text{: Primary user present.} \end{array}\right\} \quad (1)$$

Hypotheses take signal under this form

$$\left.\begin{array}{ll} H_0 : Y[n] = W[n], & n = 1, \ldots \ldots, N \\ H_1 : Y[n] = X[n] + W[n], & n = 1, \ldots \ldots, N \end{array}\right\} \quad (2)$$

Where,

Y[n] – Two dimensional vector with the received signal I, Q component.

W[n] – Zero mean additive white Gaussian noise (AWGN) with the variance σ_n^2

$\sigma_n^2 - W[n] \sim N(0, \sigma_n^2)$

X[n] – Signal sent by the PU after attenuation from the channel.

N – Number of samples of the received signal.

After comparing a test statistic T with a threshold 'λ' can made decision between two hypotheses.

Probability of detection, PU is present, when the spectrum is occupied by the PU, declared by SU [16].

$$P_d = P\{T(Y) > \lambda | H_1\} \quad (3)$$

Probability of false alarm (P_f), the probability of SU identified that a PU is present when the spectrum is actually free.

$$P_f = P\{T(Y) > \lambda | H_0\} \quad (4)$$

Probability of miss detection (P_m), the probability of a SU identified that a PU is absent while the spectrum is in use.

$$P_m = P\{T(Y) < \lambda | H_1\} \quad (5)$$

Probability of error, sum of P_f and P_m

$$P_e = P_f + P_m \quad (6)$$

Time period provides accurate detection in less duration of time for flexible communication.

T – *Frame size*

T_s – *Sensing time*

T_r – *Reporting time*

Time frame used to transmit data $T_t = T + T_s + T_r$. If more time the data has been transmitted means high throughput can be achieved [16].

Table 1
Hypothesis outcomes

Actual State	H_0: PU is absent	H_1: PU is present
H_0: PU is absent	True	False
H_1: PU is present	False	True

5. SPECTRUM SENSING TECHNIQUES

In this paper various types of spectrum sensing (SS) methods are given. At the same time important SS schemes like, single user, primary transmitter detection, cooperative methods are discussed in detail, it helps to develop a new SS technique.

5.1. Energy Detection

Another name of Energy Detector is radiometry and periodogram [4]. In order to identify the presence or absence of PU based on the received signal energy has been compared to the already known threshold value 'λ' in a regular interval [23]. It is a simplest detector and it has low complexity, and low delay. There is no need for prior knowledge about the PU signal because it is a non coherent method. If the received signal is greater than the threshold 'ë' value means PU is available otherwise PU is not present [24],[25]. Here, noise role is very important one, so we must know the knowledge about noise power. The test statistics equation is given below,

$$T(Y) = \frac{1}{N}\sum_{n=1}^{N}\{Y[n]\}^2 \tag{7}$$

Where,

N = τf_s –Sample size (or) Number of available samples.

τ – Sensing time, f_s-Sampling frequency.

$T_y(N) > \lambda$ = Present of PU

$T_y(N) < \lambda$ = Absent of PU

SU don't have a prior knowledge about the PU signal and it's detected any zero mean constellation signals [26].

5.2. Matched filter detection

SU knows a prior knowledge about the PU signal means it's called Matched filter detection and also it maximize the received signals, signal to noise ratio (SNR)[17]. It is obtained by correlating a known signal with an unknown signal to detect the presence of the unknown signal. This is equivalent for unknown signal with a time-reversed manner. It is a coherent based detection, so it needs less time to achieve high processing gain at the same time it needs dedicated sensing receiver for all PU signal types [26]. The matched filter operation can done by using the following expression,

$$Y(n) = \sum_{k=0}^{\infty} h(n-k)x(k) \tag{8}$$

Where,

x – Unknown signal convolved with maximum SNR.

It is a linear filter, and it can maximizes output SNR for given input signal [27]. To compare the signals and get the desire places, taking FFT, and multiply their co-efficient values, finally taking IFFT means got the output. This technique is not appropriate. It takes less time to achieve detection and processing gain.

5.3. Cyclostationary Detection:

Cyclostationary Detection (CD) is widely used, to compare Energy detection method for noise uncertainty condition. It can able to detect signal at very low SNR values by develop the information embeds in the received primary signals. A signal is identified by cyclostationary scheme and its autocorrelation is a periodic function of time 't' [28]. Due to the periodic function, these cyclostationary signals show features of periodic levels [29] along with spectral correlation, meanwhile it cannot identify the stationary noise and interference. Received signal cyclic autocorrelation function (CAF) analysis used to realize stationary noise.

$$R_x^{\propto}(\tau) = E[x(t).x^*(t-\tau).e^{-j2\pi \propto t}] \tag{9}$$

Where,

E(.) – Expectation operation.

* – Complex conjugate.

– Cyclic frequency.

Fourier series can also explains the function CAF, name is called cyclic spectrum density (CSD) function as,

$$S(f,\propto) = \sum_{\tau=-\propto}^{\propto} R_x^{\propto}(\tau).e^{-j2\pi\propto t} \tag{10}$$

If cyclic frequency $\propto_{\zeta}$, is equal to the basic frequency of transmitted signal, peak has been revealed CSD function. If non-cyclostationary noise means no peak has been revealed under hypothesis H_0 [30]. This method is used for detecting weak signals with very low SNR and it identifies noise from primary signals, not applicable for matched filter and energy detector.

Scanning the cyclic spectrum or its CAF is mainly used to identify the PU signal. Primary signal presence or absence decision can make by comparing cyclic spectrum or CAF to CF with the threshold value.

5.4. Wavelet Detection

It is a mechanism to analyze multi resolution, here input signal is changed in to different frequency components, and each component is analyzed with resolution matched to its scale. Sine and cosine functions are used in Fourier transform, but wavelet transform use irregular wavelets as basic function, it will give better tool to represent minute changes [31]. It carries important information on power spectral densities (PSD) and frequency locations [32].Various types of frequency components only exhibits by Fourier transform not for the location. The PSD can show the sharp changes near the boundaries of the channel of the PSD shape. Edge is present will represent PU presence on the band [11]. Received signal PSD expression is given below,

$$S_r(f) = \sum_{n=1}^{\infty} \propto_n^2 s_n(f) + s_w(f), f \in [f_0, f_n] \tag{11}$$

$\propto_n^2$ – Signal power density within the n^{th} band.

$s_n(f)$, $s_w(f)$ – PSD of signal and noise.

$f \in [f_0, f_N]$ – Wideband frequency range.

It can easily to adapt dynamic PSD structures, but higher sampling rates required to characterize entire bandwidth.

5.5. Waveform based detection:

In this method, to construct some data’s to done the detection, [16] those are follows

Preambles – collection or set of data patterns with known bits.

Mid ambles – middle of the transmitted data.

Pilot – Signature signal sent by PU.

These coherent sensing methods have knowledge about the presence of known signal, received signal Compared to the known signal parameters in this manner it has been detect the presence and absence of a PU [8], [9]. To increase the length of the known patterns will be increased the detection accuracy. This waveform obtained in the form of metric revealed below,

$$M = R\left[\sum_{n=1}^{N} Y(n)\,x^*(n)\right] \tag{12}$$

Where,

* – Represent conjugate operation.

R – Real part.

Table 1
Comparison of various spectrum sensing techniques

Sensing Techniques	Narrow band (NB)/ Wideband (WB) Sensing	Prior signal Know-ledge	Sensing Accuracy	Communi-cation Flexibility	Comput-ational com-plexity	Sensing time duration	cost	Power consum-ption
Energy Detector	NB/WB	No	Very low	Very low	Very low	Very less	Very low	Very low
Matched filter Detection	NB	Yes	Very high	Very high	Low	Less	Low	Medium
Waveform based Detection	NB	Yes	Low	Low	Medium	Medium	Medium	Low
Eigen value based Detection	NB	Yes	Very low	Very low	Low	Less	Medium	Medium
Wavelet based detection	WB	Yes	medium level	Medium	Very high	Very large	Very high	Very high
Cyclostationary based detection	NB	Yes	High	High	High	Large	High	High
Multi-Band cooperative sensing	NB/WB	Yes	High	High	Very high	Very large	Very high	Very high

Each technique analyzed and compared by using some important parameters. This comparison is very helpful for the author's, because those parameters are play a vital role in real time applications.

5.6. Eigen-value based Detection

In this method based on the statistics additionally it will be classified in to three.

Min-max Eigen-value Detection: It is defined as the ratio of

max to min Eigen value of covariance matrix.

Energy with min Eigen value: It is defined as the ratio of average power to min Eigen value of the received signal.

Max Eigen value detection: It is obtained by max Eigen value. Each SU can be used Eigen values of covariance matrix.

The received signal covariance matrix of the samples is,

$$R_{x(N_s)} = \frac{1}{N_s}\sum_{n=L-1}^{L-2+N_s} \widehat{Y}(n)\widehat{Y}^*(n) \tag{13}$$

Where,

N_s – Collection of number of samples.

$\widehat{Y}(n)$ – Estimated received sample signal.

$\widehat{Y}^*(n)$ – Transpose conjugate of.

L – Smoothing factor.

It takes long time for sensing to compare Energy detection and computation is more complex.

5.7. Multi-Band sensing

In this method to sense an only one narrow band at a time but to concentrate multiple bands by CR users. To done the multi-band sensing means an energy detector is essential for all band of interest. This sequence makes a higher hardware cost, if the number of bands of detection is high. Here, [2] spatio-spctral joint detection scheme is used; the statistics of sensing K bands from M spatially distributed CR users.

6. CONCLUSION

Spectrum sensing, here both cooperative and non cooperative sensing is an very efficient method to increase the detection performance. Cognitive radio has proved to utilize the spectrum usage level, and the important feature spectrum sensing was explained. In this paper surveyed and reported system performance and each sensing technique has been compared by using an important parameters, considered for real-time operations. In real-time environments, large objects makes shadowing, multipath fading, pilot to decrease signal strength and increase unwanted signal levels, it will increase the sensing time duration and false identification reduce sensing flexibility. This survey work can help as a reference for working in spectrum sensing technique. Further, we are going to identify the research hazards and unresolved problems in spectrum sensing, that may help for future research.

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