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AN OVERVIEW OF COGNITIVE RADIO ARCHITECTURE A REVIEW

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ABSTRACT

Cognitive Radio (CR) is a technique which is used to improve the utilization of the radio spectrum. It is a software controlled radio that senses the unused frequency spectrum at any time. The main problem in cognitive radio is spectrum sensing. In this paper, the comparison of different techniques for spectrum sensing and transceiver from different perspectives is presented and a new architecture is suggested, which can give a better hardware resources utilization and also spectrum sensing time can be reduced.

Keywords: *Cognitive Radio, Spectrum Sensing, OFDM, Transciever.*

1. INTRODUCTION

The radio spectrum is one of the most precious natural resource. Wireless networks today follow a fixed spectrum assignment strategy. The use of the spectrum is owned by government agencies. This results in a large portion of assigned spectrum being used only intermittently or not at all [1]. This leads to the invention of Cognitive Radio (CR), in which the secondary users are allowed to use the licensed bands without causing interference to the licensed or primary users [2, 3, and 4]. CR is equipped with spectrum sensing technique to find the unused part of the radio spectrum. The CR network performance depends on the essential factors such as speed and accuracy of spectrum sensing techniques. CR transceiver configurability is necessary for the radio to operate in different communication modes based on available spectrum bandwidth and wireless channel condition, hence, leading to better spectrum utilization.

The main functional blocks used in cognitive radio are: Spectrum sensing, Management, Mobility and Sharing. Spectrum Sensing is used for detecting the unused spectrum and allocating it to the secondary user without causing harmful interferences to other users. Spectrum Management is the technique of obtaining the finest available spectrum to meet user requirements whereas not creating unnecessary interference to the primary user. Spectrum Mobility is defined as the process of maintaining flawless communication during the changeover to better spectrum. Spectrum Sharing is the process of distributing the spectrum hole reasonably to the unlicensed user. Orthogonal frequency division multiplexing [OFDM] is most widely used technology for transmission and reception in current and future wireless communication systems. It can provide high transmission bit rates and good protection against interferences.

2. SPECTRUM SENSING

The Secondary User (SU) will continuously monitor the Primary User (PU), and if it is free it will engage otherwise, SU will quit that particular PU and switch to another frequency band to avoid intrusion. This technique is known as spectrum sensing. Spectrum sensing can be classified as: transmitter detection, cooperative detection and interference based detection [5].

2.1. Cooperative Detection

Works by combining the observations of several CR users. It improves the performance of spectrum sensing [6].

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2.1.1. Centralized coordinated technique

One CR will identify the presence of a primary transmitter or receiver. This information will be conveyed to the CR controller which is a wired immobile device or can be a new CR user. The CR controller monitors all the users in its range by a control message. They are classified as: **Partially cooperative** in which network nodes will only assist in channel sensing. **Totally cooperative** scheme where network nodes will sense the channel and in addition, it will cooperate in relaying each other‘s information [7].

2.1.2. Decentralized coordinated technique

In the absence of the controller a cognitive network is designed in this technique. Gossiping algorithms or clustering schemes are used in this technique. In clustering algorithm cognitive users gather to clusters and auto coordinating themselves [8].

2.1.3. Decentralized uncoordinated technique

In this method, the cognitive users don‘t have cooperation. Each user will independently identify the channel. When a CR user detects a primary user it will vacate the channel immediately without intimating the other users. Hence, CR user's experience bad channel realizations and spot the channel imperfectly thus causes interference at the primary receiver.

The advantages are: Embedding cooperation between nodes can reduce the detection time Compared to uncoordinated detection. Disadvantage in this technique is that it requires dedicated hardware for cooperation, which will increase the hardware cost. It also needs control channels.

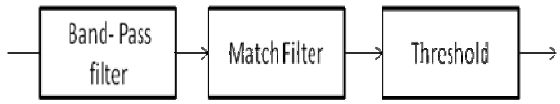
2.2 Non-cooperative or Primary Transmitter Detection:

Primary users are detected based on the signal received at CR User-receiver.

2.2.1 Matched filter detection

This is a linear filter used to maximize the output SNR for a given input signal. The input signal x(t) is passed through a band-pass filter. It measures energy around the related band. The output is convolved with the matched filter whose impulse response is same as the reference signal. The matched filter output value is compared to a threshold value to detect the presence or absence of primary user. This method can be used in case when the primary user‘s information is known. It needs less detection time and the limitation is that it requires prior knowledge of every primary signal. If no information is accurate, this technique works poorly. Also each CR needs a dedicated individual receiver for every type of primary user.

Figure 1. Block Diagram of Matched filter



2.2.2. Energy Detection

The input signal is filtered using the band pass filter to select the bandwidth of interest. The output signal is squared and then integrated over the observation interval.

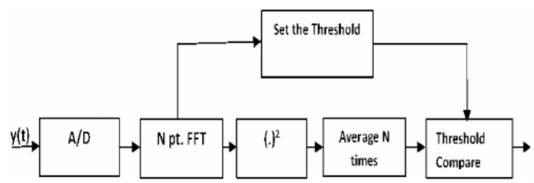


Figure 2. Energy Detection Block Diagram

The output of integrator is compared to a threshold level to find out the presence of primary user [9]. It does not need former knowledge of primary user signal, and it can be implemented easily. The limitations are the sensing time is high, and the performance of the energy detector is highly susceptible to noise. The major challenge in this technique is to set the right threshold for detection.

2.2.3. cyclostationary feature detection

In this detection technique, CR can distinguish between noise, and user signal by analyzing its periodicity [10]. The periodicity is embedded in sinusoidal carriers, pulse trains of the primary signals. The filter is used to measure the energy around the related band and then FFT is computed. Correlation block will correlate the signal and feature.

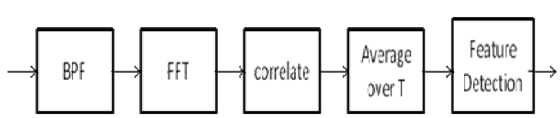


Figure 3. Block Diagram of Cyclostationary feature detection

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The main advantage of the feature detection is robustness to noise and it can categorize the noise energy from the modulated signal energy. The technique requires long observation time and more complex, which results in high cost.

2.2.4. Covariance based s ignal detection

The main idea is that to exploit the covariance of signal and noise because the statistical covariance of signal and noise will be different [11]. The steps of this technique are given: Initially sample covariance matrix for the received signal is calculated. Then, two test statistics are extracted from the sample covariance matrix. Finally, a conclusion on the signal presence is done by comparing the ratio of two test statistics with a threshold. This is complex and requires more sensing time.

2.2.5. Random hough transform based detection

The Hough transform is used for pattern detection in image processing. This technique has been proposed for CR [12], where the signal received by Random Hough transform can be used for finding the presence of radar pulses in IEEE 802.11. If some patterns related to primary users are identified, CR users assume that PU uses the spectrum. Otherwise, CR users will assume that the band is idle for given time and location.

2.2.6. Radio identification based detection

This technique is used in the European Transparent Ubiquitous Terminal (TRUST) project, based on extracted features such as transmission range, transmission frequency, and modulation technique. Once these features are extracted from the received Signal, Users can select suitable transmission parameters by exploiting those features according to the Sensed information.

2.2.7 Waveform-based detection

In this approach, the patterns corresponding to the signal, such as transmitted pilot patterns, preambles are used in wireless systems for synchronization or to detect the signal presence. When a known signal pattern is found, the detection method is applied by correlating the received signal with an identifiable copy of itself [13]. This method is known as waveform-based detection.

$$D = \mathrm{Re}\left[\sum_{n=1}^{N} y(n)s^*(n)\right] = \sum_{n=1}^{N} |s(n)|^2 + \mathrm{Re}\left[\sum_{n=1}^{N} w(n)s^*(n)\right]$$

The first term is the signal, second term is noise. If s(n)=0 , indicates that the primary user is idle, if s(n) $\neq$ 0 then is user is busy. This is superior than energy based detection in terms of reliability.

2.3. Interference Based Detection

2.3.1 Primary receiver detection

When receiving the data from the primary transmitter the receiver will emit the local oscillator leakage power from its RF front end. Primary signal can be detected using this leakage power [14]. By mounting a low-cost sensor close to a primary user's receiver the presence of primary user can be detected. The leakage power expelled by the RF of the PU's receiver, which presents within the CR system range, will be detected by the sensor. The local sensor informs the sensed report to the CR users in order to identify the spectrum occupancy status.

2.3.2 Interference temperature management

The primary and secondary users co-exist and transmit their data simultaneously. This method is the best technique for shielding the licensed users from the interferences caused by secondary users [15]. The idea is to locate an upper interference range for a given frequency bands such that the users are not allowed to cause harmful interference. This method can avoid the hidden terminal Problem. The disadvantage is that the cognitive radio users cannot distinguish between actual signals from the primary users and noise or interference.

2.4. Other Signal Processing Approaches

These are the one which do not fix in above categories are multi-taper spectrum sensing, wavelet-based detection and filter bank based spectrum sensing.

2.4.1. Multi-taper spectrum sensing and estimation

In this technique, the last N received samples are collected in a vector form and are represented as a set of slepian base vectors. The Slepian base vectors are used to identify the spectrum

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opportunities in the targeted spectrum band. The Fourier transforms of Slepian vectors have maximum energy concentration in the bandwidth fc-W to fc +W. By analyzing it, CR user can detect the spectrum holes.

2.4.2 Filter bank based spectrum sensing

Filter bank based spectrum estimation (FBSE) is considered as simplified version of MTSE. MTSE is better for small samples whereas FBSE is better for the huge number of samples [16].

2.4.3. Wavelet detection

For the detection of wide-ba nd signals, the wavelet approach is advantageous in terms of both implementation cost and flexibility. The spectrum is decomposed into smaller sub-bands to apply the wavelet- based approach to detect the edges in PSD. In this, the edges on the PSD are the separator of occupied bands and spectrum holes for a given time and location. Based on this information, SU users can identify spectrum holes.

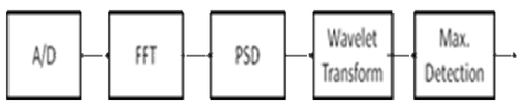

Figure 4. Block Diagram of Wavelet detection.

3. COGNITIVE RADIO TRANSCEIVER

After sensing the spectrum it should be transmitted by the PU and received by the SU. CR is considered as an advanced version of software defined radio (SDR) in which the functionality can be altered with the help of software. The role of modulation techniques in an SDR is essential since modulation techniques define the core part for the wireless technology. Several modulation techniques are available.

3.1. BPSK Transceiver

In Binary Phase Shift Keying, phase of carrier signal changes abruptly by 1800 or π radian for every transition of input modulating signal. Hence, it can send only 1 bit per symbol. Compared to other modulations schemes, BPSK can provide better SNR [17].

3.2. QPSK

Many communication standards use the Quadrature phase shift keying (QPSK) modulation due to robustness against noise and very high data rate. It is used as a modulation scheme in 3G wireless communications, WiMAX, WiFi and in satellite communication. It sends a couple of bits per symbol, which increases data rate factor by two and hence the bandwidth efficiency is twice that of the BPSK. The phase of the carrier changes as π/2 , π and 3π/2.In QPSK, two data channels modulate the carrier represented as an in-phase component, $I(t)$, and an out-of-phase component, $Q(t)$.The transceiver system consists of 5 parts: symbol generator, interpolator, up converter, down converter, carrier recovery block and decimator. The problem at the receiver communication is carrier synchronization. To solve this, phase locked loop circuit must be added to the receiver. The common problem in signal communication is Inter Symbol Interference (ISI). So raised cosine signaling is a type of pulse shaping filter, which can be used in to reduce ISI [18]. QPSK modulation technique provides twice the spectral efficiency. Differentially Encoded QPSK (DQPSK) modulation scheme is widely used in the various communication standards due to its high its power and bandwidth efficiency [19].

3.3. FSK and QPSK

QPSK and Frequency Shift Keying (FSK) configured together it will yield a good results. For configuring the whole architecture either as FSK or as QPSK a switch is used [20]. Two selection lines are used to select the Tx-Rx part and either FSK or QPSK part. At the receiver, the antenna receives the modulated signal which is then converted to digital data using ADC. Output is the resultant original digital data signal that is transmitted from the transmitter. QPSK gives poor BER but FSK gives very good BER providing high data rate.

3.4. QAM

Quadrature Amplitude Modulation (QAM) is the as a combination of ASK and PSK [21]. It is the method for sending two separate channels of information. The outputs of both channels are summed and give a single signal, containing the In-phase (I) and Quadrature (Q) information. QAM has the best BER. For the high-rate transmission, QAM can be used for better transmission performance.

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4. PROPOSED ARCHITECTURE

4.1 Transceiver Architecture

From the above discussion, it could be seen that the proposed transmitter and receiver architecture can be better and will improve the performance of cognitive radio spectrum sensing and transceiver. The use of OFDM based transceiver provides spectral efficiency, which is an important requirement for CR system. This is because of sub carriers are very closely spaced and overlapped. By using OFDM technique the transmission parameters like FFT size, filters, windows, modulation and transmit power, etc. can be changed due to its flexibility and adaptive in nature. It also provides high transmission bit rates and good protection co-channel interference.

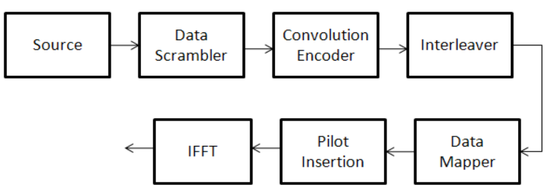

Fig. 5 OFDM Based Transmitter

In the OFDM based transmitter, first encoding process is done using scrambling, encoding, interleaving and puncturing, of input data to achieve higher data rates. The interleaved data string is transformed into a complex number.

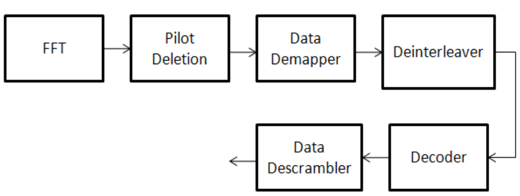

Fig. 6 OFDM Based Receiver

Then it is divided into of 48 complex numbers and mapped to OFDM subcarriers. Next in pilot insertion block, 4 pilot subcarriers and 1 zero DC subcarrier are inserted among 48 data subcarriers which are then enclosed with 11 zero guard subcarriers to form an OFDM symbol. The next block converts the subcarriers to time domain using Inverse Fast Fourier Transformation (IFFT), and it extends itself to form cyclic prefix. The receiver performs reverse operation of the transmitter. It can be implemented in hardware [FPGA].

4.2. Spectrum Sensing Architecture:

In the proposed spectrum sensing technique, first the primary users are generated by the sine wave generator at different frequencies. Then it is given to buffer unit, which redistributes the data of the input to produce an output with a different frame size. The signal is buffered to a smaller frame size yields an output with a faster frame rate than the input. The Peak Finder block counts the number of extrema in the input signal. Then the output is squared, and then logarithm value is taken. The priority block will decide which primary user is using the spectrum and which user is not using (idle).

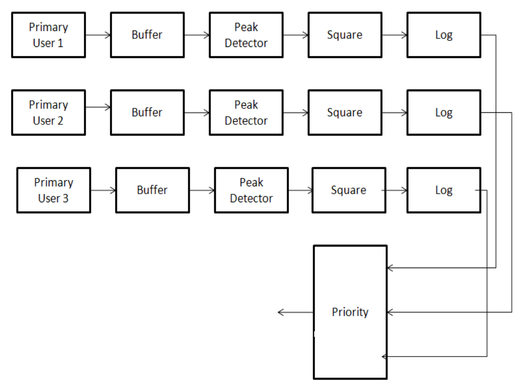

Fig. 7 Block Diagram of Spectrum Sensing

The above discussed system may be less costly, and more performance oriented. The spectrum sensing time can be reduced

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