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Realization of Spectrum Sensing in Cognitive Radio

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Abstract: The radio spectrum is becoming increasingly rare. The demand and needs of new wireless applications are escalating dramatically; likewise, the bands less than 3 GHz are extremely sparse. Radio spectrum has become bottleneck that could obstruct the new wireless communication system. According to the survey conducted by Federal Communication Commission (FCC), a huge number of bands are underutilized, ranging from 15 to 85%, while few bands are overloaded. Therefore, the concept of Cognitive Radio was developed to overcome the problem of low spectrum utilization and to solve the spectrum congestion problem effectively. The implementation of Cognitive Radio assures the full utilization of spectrum for secondary user, when the primary (licensed) user is not available. Spectrum sensing is a function of Cognitive Radio, which primarily is responsible to sense and analyze its spectrum environment, then it detects unused spectrum in licensed band. This paper demonstrates Energy Detection technique of spectrum sensing which requires no previous knowledge of received signal. Energy Detection algorithm is implemented on Raspberry pi through MATLAB 2014 to analyze the cognitive radio network.

Keywords: Cognitive Radio, Energy Detection, PSD, Spectrum Sensing, Channel Utilization, Raspberry pi.

I. INTRODUCTION

With the need of radio applications, the accessibility of radio spectrum is becoming additional expensive. Few unlicensed band were left to open for future use but with the rapid development in personal wireless technology these bands are now congested. Cognitive Radio (CR) is a self-maintaining process without any human involvement, was first proposed by Joseph Mitola III and Gerald Q. Maguire, Jr [1]. After the introduction of CR, it has been adopted by spectrum regulatory authorities such as FCC. Many researchers and research academics contributed in CR and related projects. They started to find the methods to share the spectrum. There are two models of spectrum sharing [3]:

Owned - The spectrum is handover to service providers after the auction of spectrum.

Common - After the agreement upon etiquette the spectrum can be used.

The conventional (owned) method is being implemented but it is still insufficient. As the allocation of spectrum to each wireless application is fixed, so it will be difficult for new and existing wireless technology to be allocated in new band. The OSA (opportunistic spectrum access) and DSA (dynamic spectrum access) methods are being focused by researchers. This problem of fixed allocation has urged authorities to find any method where secondary user (SU) efficiently utilizes the spectrum gap in primary user (PU) licensed spectrum band. In 2003, FCC organized the group for working in CR. In 2004, the access of white space in TV broadcast band is allowed by FCC. Defense Advanced Research Product Agency (DARPA) sponsored Next Generation program in which Filtered Multi-Tone (FMT) CR system is proposed [9]. After research and development in the field of CR, still strong coordination is required between authorities and research academia. On the other hand, IEEE standardized as 802.22, started the group working on TV spectrum and made the access to the secondary system [4].

One of the natural forms of CR is that the secondary user is equipped with the capability of spectrum sensing. Cognitive Radio is supported by dynamic spectrum access, which selects ideal free channel. After selecting the channel, other functionalities are required for adapting available spectrum [5]. Cognitive radio has some specific functionalities, which have been presented as follows;

Spectrum Sensing: The purpose of this function to detect the white space or spectrum gap and share to secondary user without any disturbance to primary channel.

Spectrum Management: Finding the ideal free channel according to the need of user.

Spectrum Mobility: Provides consistent communication by handover to better spectrum channel.

Spectrum Sharing: There are number of secondary users, to share available channels. The policy or fair spectrum scheduling requires for it.

Figure 1, provides the cognitive radio cycle using all four functions.

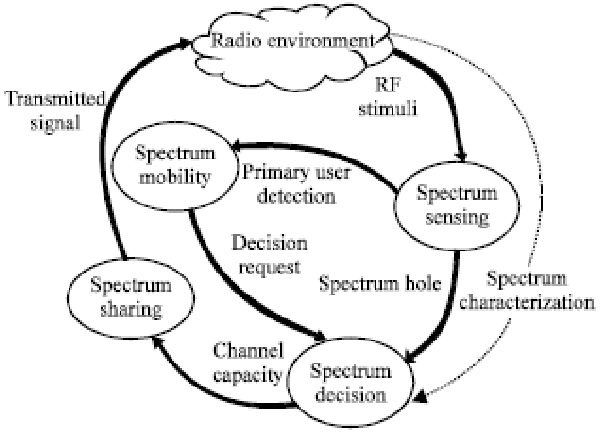

Fig. 1 Cognitive radio cycle.

II. COGNITIVE RADIO

Before defining the cognitive radio, it is necessary to get familiar with the significance of related term ‘cognition’. As per multidisciplinary study of cognition, it is a basic theory of intelligence through simulated procedure, termed as learning by understanding [10]. FCC characterized as “a radio that can adjust its transmitter parameters based on current condition”. According to Simon Haykin’s [2], Cognitive Radio is an Intelligent Wireless Communication which is defined in terminological steps. First, awareness, the radio is aware of its outside environment. Second, learning, that is acquiring information from environment. Then, adapting, that is changing the parameters of communication (like frequency carrier FC, modulation and signal power) by maintaining the reliability and efficiency of communication. The implementation of these key steps is attainable today.

Two under construction characteristic of cognitive radio are:

Cognitive Capability: The first capability of cognitive radio is to sense or detect the important parameters according to its radio environment. Sensing in terms of power of particular channel is not enough. More advanced technique is required to monitor all variations and to avoid interference.

Re-configurability: The radio environment differs with respect to time. So, the radio must be designed with re-configurability characteristic to operate dynamically. CR needs to have that transceivers architecture which must be holding novel radio frequency (RF).

III. SPECTRUM SENSING METHODS

Very first step of cognitive is spectrum. The main task includes the detection of primary user in given spectrum and sending of this information to cognitive radio [8]. Primary user is the licensed user for which the spectrum band is allocated. The radio spectrum changes its behavior dynamically so it must be designed accordingly. The collected RF spaces put into power spectra as it analyzes the power and interference of signal which categorizes as [2]:

Black space, which is captured by high power interferers. Grey space, which is partially captured by low power interferers. White space, that is free from RF interference but the natural or thermal noise could be included.

For detection of white space, many detection techniques proposed [6] are classified below:

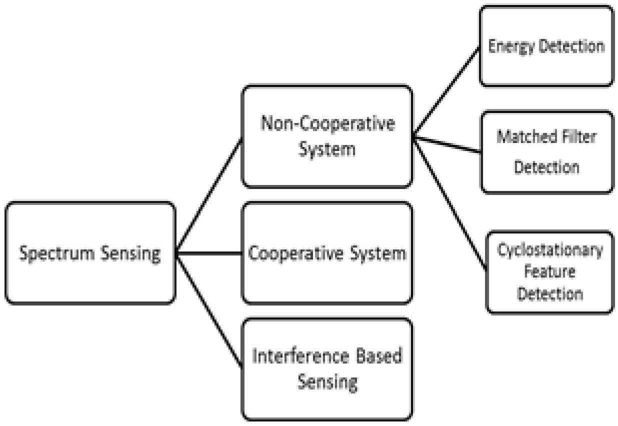

Fig. 2 Classification of Spectrum sensing technique.

From the above figure, the spectrum sensing is divided into three main sensing systems, such as interference based detecting system, cooperative system and non-cooperative system. Matched filter detection, energy detection and cyclo-stationary feature detection are sub-division of non-cooperative system.

A. Non-Cooperative System

In transmitter detection, every CR should be able to decide whether the PU in a predetermined spectrum is present or not [12]. The probability of detection (PD) and probability of false alarm (PF) in terms of two performances matrices are utilized to accumulate detecting results. PD implies the accessibility of PU. While, PF evaluates SUs probability which declares that a PU signal is available in the spectrum while PU were not utilizing the spectrum [13].

Energy Detection

It’s a kind of non-coherent detection method based on Neyman-Pearson approach. Energy detection is famous due to its simplicity and easy implementation. This technique works on estimating noise-power or energy of received signal and comparing it to the fixed or variable threshold. On comparing to the threshold, the detector decides whether the PU is present or not. If the detector's output is below threshold level, it shows there is no PU and if its above threshold level it indicates that primary user is present. The working is based on the Fast Fourier Transform (FFT), in which power spectra is calculated. Later, the threshold of signals is compared to check either the channel is free or not. The representation of energy detection technique is given in figure 3 and 4 [7]. The signal at first is calculated as power spectral density using FFT, then the signal is passed from band pass filter and integrated over time interval. After integration, the predefined threshold would be compared, to analyze either the channel is vacant or not.

Furthermore, ED has low intricacy and does not include any complex signal processing. ED is strong to the variation of the primary signal since it requires no previous information of primary signal. The best identifying method for any zero-mean constellation signals is energy detection method, when the former information of PU signal is not known [16]. Due to above reasons of energy detection as compared to other techniques, this technique is implemented.

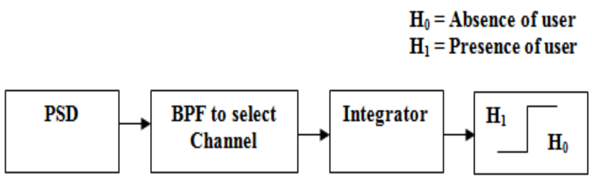

Fig. 3 Representation of energy detector in block diagram.

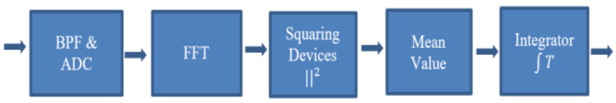

Fig. 4 Frequency Domain Representation of Energy Detection.

Cyclostationary Detection

This technique signifies, the periodicity of signal is utilized to determine the transmission of primary user. For this purpose, this method used cyclic-correlation technique so noise can be eliminated from PU signals. Cyclostationarity based technique is utilized for recognizing the distinction of transmissions among PUs. The primary downside of this strategy is the complexity of calculation. The advantage of feature detection compared to energy detection is that it typically detects noise signals and permits dissimilar signals or waveforms [13] [14].

Matched Filter Detection

In order to achieve this detection, secondary sensing node processed primary signal by coherent detection technique. For this purpose, the primary system should have tendency to demodulate the primary signals and must be synchronize to the secondary sensing system. Such prior data of primary user parameters like modulation order and type, signal shaping, which might be stored in cognitive radio memory. Matched filter achieves high processing gain in less time because of coherency [17]. At the same time, the cost of matched filter sensing design is high for sensing more than one primary spectrum [15].

B. Cooperative System

At detection side, CR sensors may detect inaccurate signals because radio signals incorporate unexpected elements like fading and shadowing. While, CR hardware unable to sense more than one channels simultaneously. To overcome this problem, CR receiver sensors cooperate their sensing signals with each other so sensing result could be more authenticate [18]. There are three types of sensing are:

In centralized cooperative sensing, all sensors result gather together at cluster or server which decides the final decision of primary user availability.

In distributed sensing, there is no need of central server because each CR sensor share intra-cluster results among rest of cluster nodes and finalize decision. That is the reason of its decreased cost [19].

In hybrid cooperative sensing, the central cluster exist which can ask cluster for any channel information, but CR sensors uses distribute system for sharing results [18].

C. Inference Based Sensing

In this sensing technique, receiver calculates the amount of interference that would occur. The interference level is balanced by adjusting the transmission power parameters, at PU receiver end. For this purpose, initial PU information requires which is computationally exhaustive [11] [20].

IV. HARDWARE AND SOFTWARE

The Energy Detection technique is implemented on Raspberry pi in our project because it is smaller in size and saves cost in comparison to FPGA and DSP. Another reason to choose Raspberry pi is that the algorithm of Energy Detection is not yet implemented on Raspberry pi. MATLAB is used as a PU or licensed user (transmitter) and Raspberry pi act as SU or unlicensed user (receiver). In this scenario, the PU has five channels. On these five channels, MATLAB randomly allocate the user and starts transmission. Raspberry pi and MATLAB are connected via Ethernet cable.

Raspberry pi after receiving the signal performs FFT and the energy is calculated. The calculated energy is then compared with the threshold defined. The threshold can be static and it could be variable depending upon the selection. If the value of energy of the channel is less than the given threshold, then PU is not present otherwise it is present. The channels which are not used by the PU are called spectrum holes.

Our working procedure is based on the following steps;

Generate Channels Randomly: Five channels are generated on different frequencies and set a center frequency for each channel. As we are not working on real spectrum, we have generated channels of our own through MATLAB.

Sensing: Spectrum is sensed by Raspberry Pi and PSD/ energy of each channel is calculated in this step by calculating the energy and summing it up.
Threshold: Fixed threshold has been set, on calculating energy of channels it is compared to a threshold.
Decision: If the calculated energy is lesser than the threshold value, it detects that PU is not present and if the calculated energy is larger than threshold it detects that the PU is present.
Allocation: On detecting which of the channels are vacant, Raspberry Pi allocates those channels to a secondary user which can use the channel until PU resumes its transmission.

V. RESULT

The cognitive radio mainly senses the unused spectrum band in spectrum that is licensed user (primary user) and allocates the unused channel to secondary user without interfering to primary user. The secondary user must leave the allocated band when primary user occupies empty slot.

As we have taken 5 random channels with carrier frequency of 1 KHz, 2 KHz, 3 KHz, 4 KHz, 5 KHz and sampling frequency of 12 MHz assigned for our simulation. The energy detector algorithm detects the existence of primary user by calculating the power spectral density (PSD) of the signal then compares with threshold.

The allocation of primary user in all 5 channels is random, so in our case 1st, 4th and 5th primary users are presented and 2nd, 3rd slots are free as shown in figure 5.

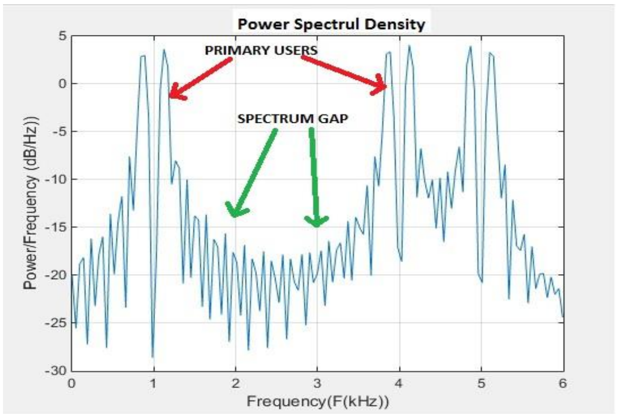

Fig. 5 Used bands (1st, 4th & 5th), and unused bands (2nd & 3rd) graph on MATLAB.

The above graph shows the detection of primary user. On x-axis frequencies are mentioned and on y-axis mentioned power. After detecting the spectrum gap in all given bandwidth, cognitive radio will look these free slots to start allocating for secondary user (SU). Low peaks of signals in Figure 5 are for 2nd, 3rd primary users who are absent. In figure 6, the allocation of SU on unused band is shown.

In figure 6, the secondary user is automatically allocated to free band i.e. 2nd and 3rd band as indicated by red color signal. Now all the slots are filled. This is the example of effective utilization of spectrum. Here the vacant band is automatically allocated by secondary user without interfering primary user transmission. Secondary user monitors primary user to make sure that whether primary user is going to use the channel or not, the secondary user information can be deleted any time for primary user.

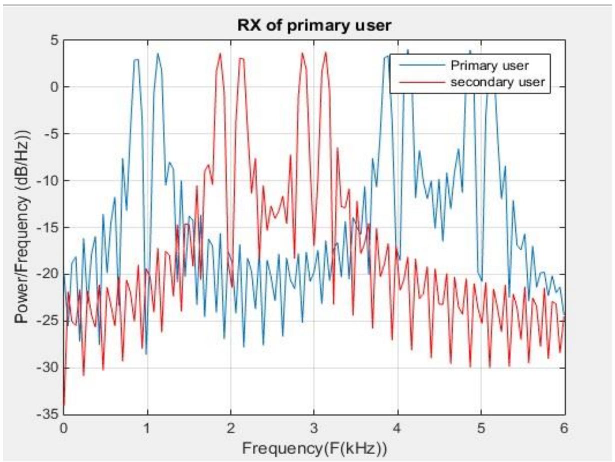

Fig. 6 Secondary user allocation graph on MATLAB.

VI. CONCLUSION

With the growing demand of data rates the natural spectrum is being congested. But upon analyzing the spectrum we concluded that licensed spectrum is underutilized. CR is the emerging technology and it provides the solution of spectrum congestion through Dynamic Spectrum Access and Spectrum Sensing. The goal of the spectrum sensing in cognitive radio is to determine the spectrum-holes. Implementation of Energy Detection method in CR is done through MATLAB and Raspberry pi. The PSD of the signal can be seen in figure 5, which is showing the status of primary users whether they are utilizing their band (by showing the peaks of respective user) or not. In figure 6, the receiver of cognitive radio starts transmission for secondary user. The peaks of each band are showing the presence or absence. This transmission is cleared from interference between primary and secondary user. Cognitive radio is an innovative technique that will utilize the spectrum effectively and globalize the radio conditions for various band users which operate different techniques for transmission. The efficiency of spectrum sensing can be increased by applying hybrid technique e.g. combining energy detection and matched filter detection technique on real spectrum.

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