Dynamic Spectrum Access using Energy Detection Algorithm

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***Abstract*—The proliferative spurt in the number of radio frequency spectrum users has led to evolution of distinct approaches to resolve the challenges of spectrum vacancy and spectrum inefficiency. The users of radio frequency spectrum are presided over by a set of intellectual systems called as Cognitive Radio (CR). They provide applicative opportunities to licensed as well as unlicensed users to harness the spectrum as per their necessities. Employment of different spectrum sensing techniques facilitates CR to function according to the demands of users. This paper deals with energy detection sensing technique to be used for dynamic access of radio spectrum. Energy detection method assists CR in the allotment of specific frequency bands for exploitation by the users. Unlicensed users are privileged by acquiring the allowance of using the spectrum when it is unused temporarily. This paper focuses on management of the allocation of users in a dynamic manner which ingeniously avoids any interference caused to licensed users in the spectrum.**

Keywords— Cognitive radio; spectrum sensing; white space; dynamic spectrum access; energy detection; primary user; secondary user

I. INTRODUCTION

The recent surge in wireless technology has led to overcrowding of available RF spectrum bands. Federal Communications Commission (FCC) has been investigating new ways to manage RF resources. To resolve the problem of spectrum inefficiency the concept of cognitive radio was introduced. Cognitive radio is an intelligent radio that senses the spectral environment and exploits this information to cater to user's communication requirements. Cognitive radios search for unused spectrum bands [1], called as white spaces or holes, in frequency as well as time where the measured interference is low enough to achieve communication at a desired capacity subject to overall interference constraint. It gathers information about transmission frequency, bandwidth, power, modulation etc. to be able to take a decision felicitously and adapts to changes in performance and surrounding environment to better serve the needs of users [2]. The technique of identifying unused radio spectrum bands and utilizing them for real-time user needs is referred to as dynamic spectrum access. It has two primary objectives viz. reliable communication in real-time and efficient spectrum use. Fig. 1 shows the white spaces or holes in the radio spectrum.

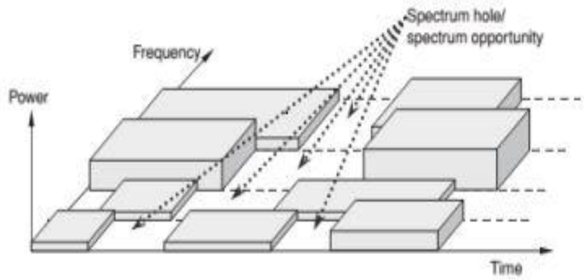

Fig. 1 Identification of spectrum holes in frequency and time domains

The RF spectrum is utilized by primary users (PU) and secondary users (SU). Primary users are licensed users that have full access to the spectrum when they need it. In contrast, the secondary or unlicensed users can utilize the spectrum when the primary users are temporarily unavailable for spectrum usage. The key feature of dynamic spectrum management [3] is to avoid interference caused by unlicensed users to the licensed ones when they are using the spectrum band. It aims to provide coexistence of licensed and unlicensed users instead of avoiding primary signals. In order to allocate available spectrum bands to primary and secondary users, the spectrum needs to be sensed for detection of presence or absence of signal at frequency bands. Spectrum sensing by cognitive radio systems is facilitated by non-cooperative and cooperative methods depending on environmental needs [4]. Non-cooperative techniques include,

a) Energy detection: energy of signal is compared with a predefined threshold to check occupancy of band.

b) Matched filter detection: prior knowledge of signal is used to detect presence or absence of user.

c) Cyclostationary feature detection: properties which are specific to a non-stationary signal are exploited to differentiate it from noise which is stationary.

This discourse proposes energy detection model of dynamic spectrum access. Energy detection is a relatively easier technique to implement because of its low computational complexity and varied applications. The proposed model aims at improving the efficiency of spectrum by providing significant opportunities to secondary users without primary users being interfered.

II. FUNCTIONS OF COGNITIVE RADIO

The cognitive radio cycle includes four fundamental functions in cyclic sequence. These functions govern the dynamic access of radio spectrum providing equal opportunity to each incoming user for utilizing the spectrum. Fig. 2 shows the four basic functions in cognitive radio cycle.

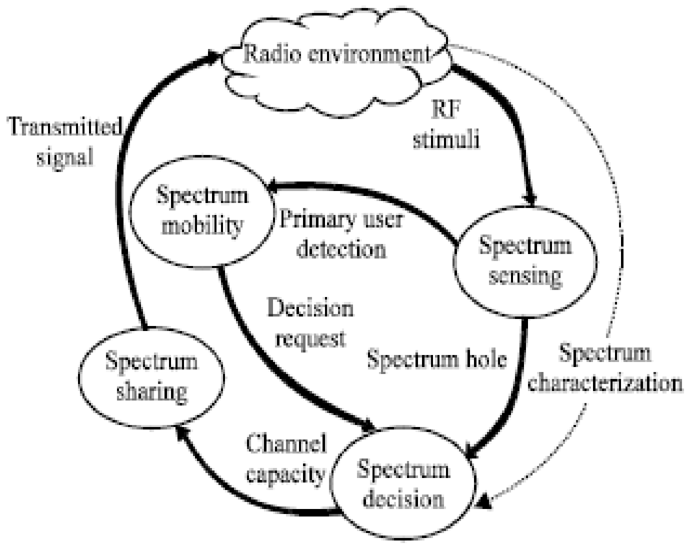

Fig. 2 Cognitive radio cycle

A. *Spectrum sensing*

The first step of cognitive radio cycle is to locate primary users in band and thus to determine vacant positions in the spectrum. CR is able to communicate the result of detection to its neighboring nodes. The primary objective of spectrum sensing is to find out the spectrum status and activity by periodically polling the frequency bands. Basically a cognitive radio transceiver senses white spaces in spectrum without hampering the transmission of licensed users.

B. *Spectrum management*

Management of spectrum involves allotment of free channel to the secondary user after detection of holes by spectrum sensing. Spectrum sensing, spectrum analysis, and spectrum decision come under spectrum management. Spectrum analysis makes possible the selection of specific frequency bands according to the need of a particular user. Spectrum decision refers to selection of a set of radio parameters like data rate, transmission mode and transmission bandwidth. After sensing and analysis of bands, appropriate spectrum band is selected according to the spectrum characteristics and user requirements.

C. *Spectrum sharing*

Cognitive radio assigns the unused spectrum or hole to the unlicensed user as long as licensed user does not use it. This property of cognitive radio is described as spectrum sharing. There are two types of spectrum sharing:

a) Underlay spectrum sharing: It is the opportunistic access of the radio spectrum with minimal transmission power so that the interference temperature above its pre-determined threshold wouldn't be raised. The licensed radio device can identify undesired signal which is below the noise and interference floor in underlay spectrum sharing. Noise floor at room temperature is -174dBm.

b) Overlay spectrum sharing: Secondary users can utilize a spectrum band for a fraction of time where partial utilization of band is done by the primary users in overlay spectrum sharing technique.

D. *Spectrum mobility*

When a licensed user arrives in the radio spectrum the unlicensed user has to vacate the band to allow the high priority user to transmit. This property of cognitive radio is described as spectrum mobility and also called as handover in wireless communication. This process allows cognitive radio to switch its frequency and concept of dynamic access comes into existence. CR after allotting bands periodically polls to get status of their occupancy which makes spectrum allotment easier; as when a licensed user is detected the unlicensed user has to be shifted to another vacant band to continue its transmission without reducing throughput. Spectrum mobility is a key function of cognitive radio cycle because interfering with other (licensed) users is illegal.

III. DYNAMIC SPECTRUM ACCESS

Dynamic Spectrum Access (DSA) is necessary in order to allocate the available bandwidth in an effective manner. The methods of assigning different fixed bandwidths to different systems do not produce full benefits of having dynamically shared bandwidths. Dynamic sharing takes into account the needs of users at the time when they require the spectrum bands through various techniques [5]. Dynamic spectrum access can help to minimize unused spectral bands or white spaces. When the primary user wants to transmit, the CR enabled device frees that band and switch to another free band [6]. This technique of dynamically accessing the unused bands for its proper utilization is known as DSA. Fig. 3 helps to understand the coexistence of primary and secondary user networks.

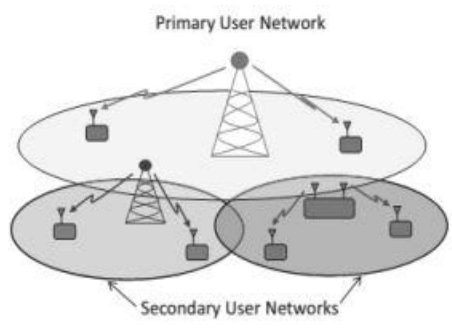

Fig. 3 Dynamic spectrum access in cognitive radio system

The concept of dynamic spectrum access is to identify spectrum holes or white spaces and use them for transmission of data. It is the core application of cognitive radio [7]. The PU bands are opportunistically accessed by the unlicensed networks such that the interference caused to the former is negligible. Coexistence of multiple primary and secondary user networks (homogeneous or heterogeneous) is an outcome of DSA. It is a technique in which a radio system adapts to available spectrum holes dynamically, in response to changing circumstances and objectives [8]. The created interference changes the radio's state in environmental constraints. The main task of DSA is to overcome two types of interference [9]:

a) Interference caused by device malfunctioning
b) Interference caused by fraudulent user

There are three main functions in DSA:
a) Spectrum awareness
b) Cognitive processing
c) Spectrum access.

Spectrum awareness creates means to be vigilant about the surrounding radio environment; neighboring nodes coordinate to share the status of bands, and band manager takes the final decision by aggregating the results. Spectrum access defines the ways to use the available spectrum opportunities efficiently [10]. Cognitive processing is the intelligence and decision making function that performs several subtasks like learning and adapting the radio environment, and access policies which manages interference level for coexistence of the primary and secondary users [11].

IV. ENERGY DETECTION MODEL OF DSA

A. Energy detection

Energy detection is a technique to specify presence or absence of user signal in the radio spectrum band. It is widely used because of its moderate computational complexities, which makes it easier to implement than other non-cooperative techniques viz. matched filter detection and cyclostationary feature detection [12]. Energy detection only requires knowledge of power of noise in the band to be sensed.

The occupancy of a band is detected by comparing the output of energy detector with a pre-determined threshold which depends on balance between probability of detection P_D and probability of false alarm P_F. P_D is the probability of detecting a signal when it is actually present in the concerned frequency band. P_F is the probability of incorrectly detecting the presence of signal when it is actually not present at the concerned frequency and vice versa.

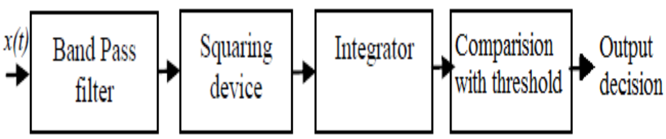

Fig. 4 Block diagram of energy detection technique

Fig.4 describes that the unwanted frequencies are removed and the desired bandwidth is obtained by passing the input signal through a band pass filter. After filtering, the amplitude of signal is then squared to obtain an estimate of the energy of signal. Integrator aggregates the energy samples over the time interval and the output of integrator is then compared with threshold value to determine occupancy of band. The band is said to be occupied if the integrator output is greater than threshold metric, otherwise it is vacant and can be used for data transmission.

B. Simulation results

Simulations for the model were performed in Matlab software where a system of cognitive radio was created, described in detail in [13]. Fig. 5 shows that the dynamic spectrum access starts with a default status of bands where every band is occupied and uses radio resources to transfer data.

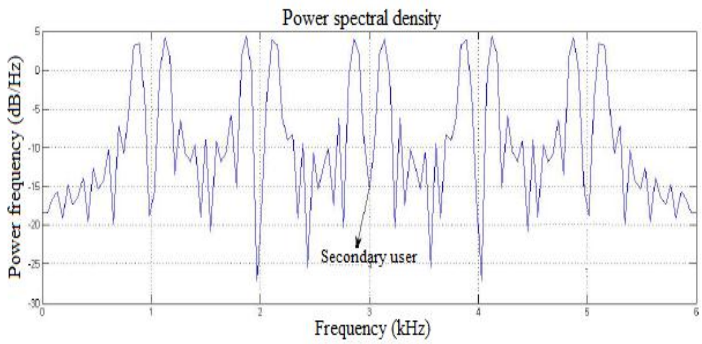

Fig. 5 PSD indicating 1st, 2nd, 4th and 5th band occupied by primary and 3rd by secondary user

When a new user arrives to access the spectrum, it is checked whether the user is primary or secondary. Depending upon the user, flow of DSA is routed through different paths as follows:

Case-'a': The new user is a primary user. The sensing nodes first check for any secondary user present in the spectrum. If a secondary user is present, it is fired and the PU replaces SU, as PU is given higher priority than SU. If the condition is false then PU has to wait for a back-off interval and again check for the status of bands. Fig.6 and 7 demonstrate the case-a.

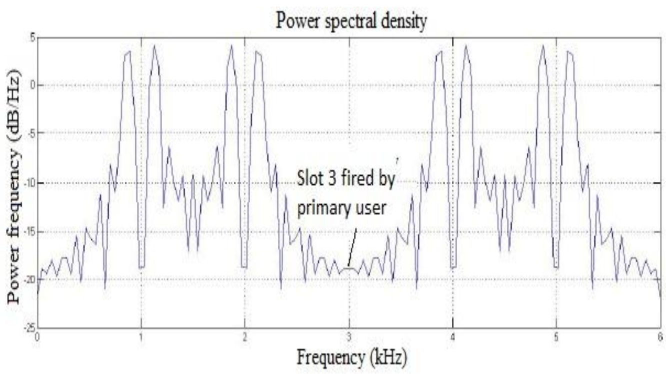

Fig. 6 PSD indicating slot 3 is fired to be occupied by incoming primary user

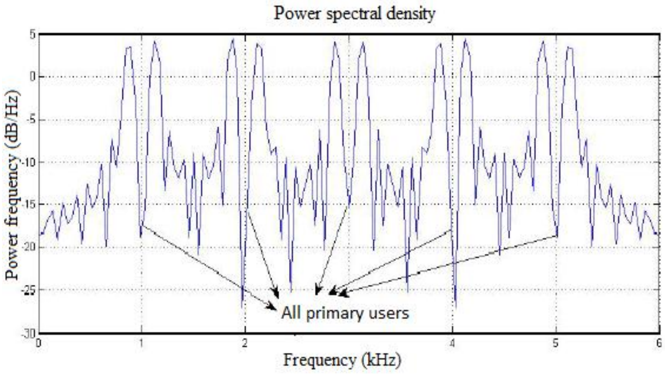

Fig. 7 PSD indicating slot 3 occupied by primary user by firing secondary user

Case-'b': The new user is a secondary user. Cognitive radio nodes check for the presence of secondary user in the spectrum. Fig. 8 shows that, if a secondary user exists, the new SU replaces the existing SU. This policy is adopted to cause minimum interference to PU and also allows coexistence of SU with PU. If no secondary user is present in the spectrum then SU has to wait for a back-off interval and again check for the status of bands. Meanwhile if PU vacates the band then SU can continue its transmission in the empty slot.

After allotment of bands, sensing nodes again check for any new incoming user and the process is iterated providing opportunistic access to each incoming user. The process terminates when there is no incoming user which provides ubiquitous transmission to existing band users. Fig. 9 shows flowchart of dynamic spectrum management model which enables coexistence of PU and SU networks.

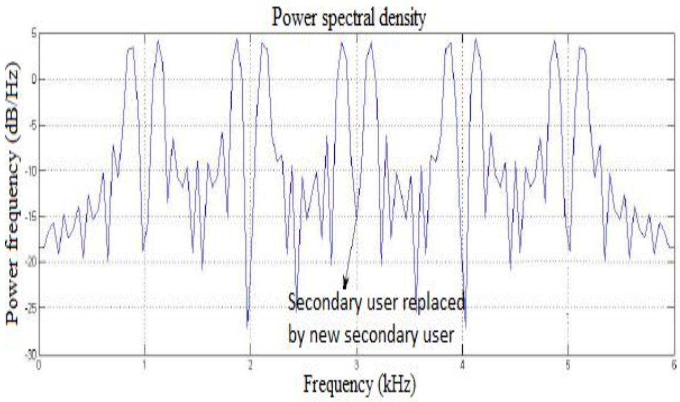

Fig.8 PSD indicating slot 3 replaced by new secondary user

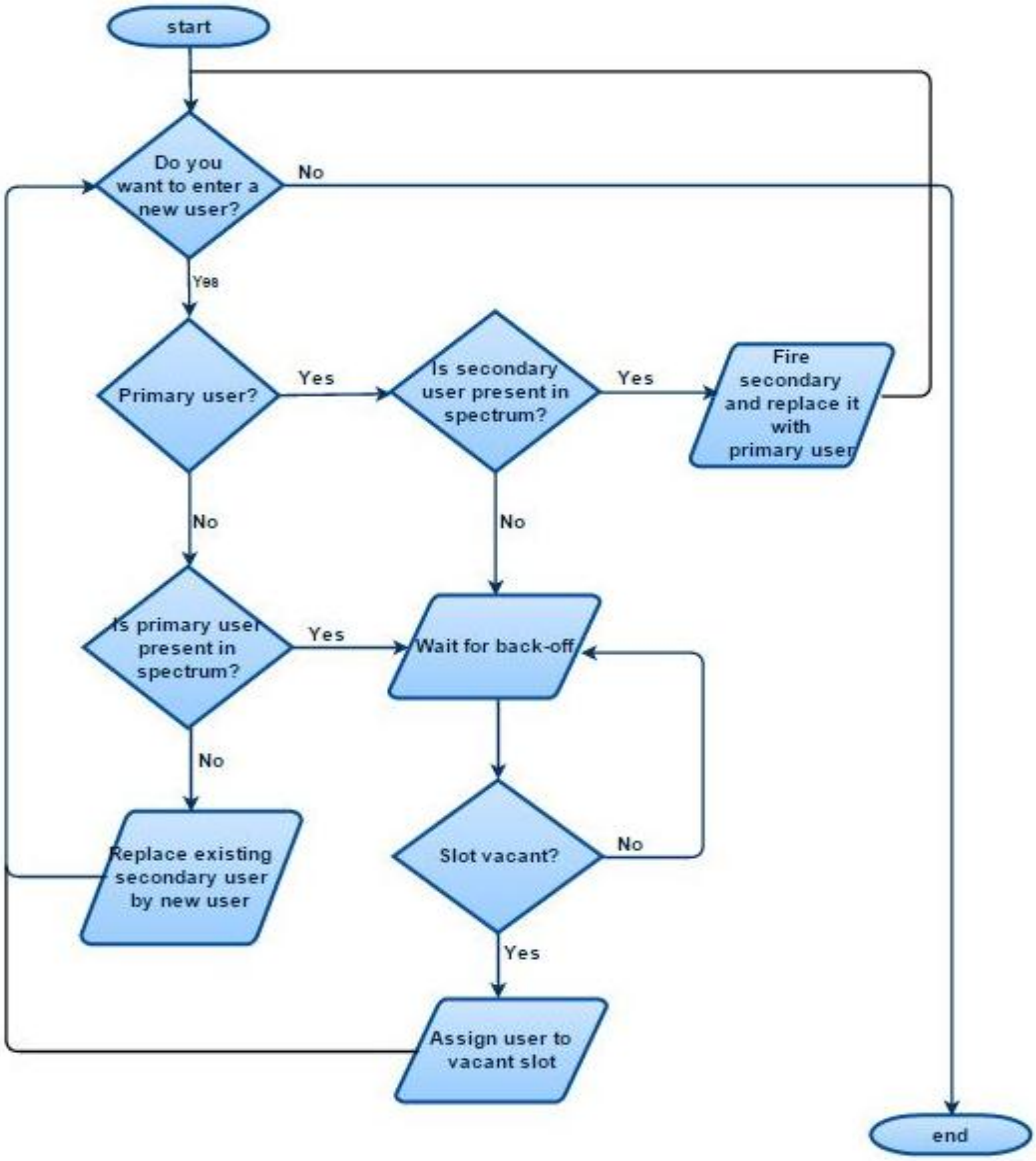

Fig. 9 Flow chart of dynamic spectrum management

V. CONCLUSION

In this paper, the spectrum opportunity and spectrum sensing concepts are re-evaluated by considering different dimensions of the spectrum space. Cognitive radio is a revolutionary technology in wireless communication catering to the needs of wireless users. As discussed above, we have implemented energy detection algorithm to detect vacant positions in the radio spectrum. This method allows dynamic resource allocation and sharing of the spectrum amongst users. The inference drawn from this paper is that spectrum efficiency can be increased, if the spectrum is used harmoniously through coexistence of primary and secondary users, with minimal interference to licensed users. The usability status of all the spectrum bands varies over time due to licensed user activities. This necessitates the use of dynamic spectrum access and management in order to facilitate communication for both licensed and unlicensed users. Real time slot status is updated to allow new user to occupy any available band without any time lag. In this paper, we have presented a model based on DSA to accommodate any new incoming user in the spectrum. It is a promising approach to minimize the spectrum inefficiency rather than physical scarcity.

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