Efficient Utilization of Vacant Spectrum using Reconfigurable Secondary Users in Cognitive Radio Network

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Abstract – In the era of entirely wireless, mobile communication technology, the demand of high-speed, high-performance has been increasing infinitely. But the radio spectrum used for wireless and mobile communications is a finite resource. Cognitive radio comes out as a solution to this problem as it allows the vacant frequency band in the licensed spectrum to be used by an unlicensed user without causing interference to the licensed user. In this paper, method of allocating the vacant spectrum to the unlicensed user, in a way to improve spectral efficiency is discussed.

Index Terms – Cognitive radio, Dynamic spectrum allocation, OFDM, Capacity, IEEE 802.16 WiMAX standard.

1. INTRODUCTION

Cognitive radio has emerged as potential technology to improve the spectral utilization. According to FCC (Federal Communication Commission), Cognitive radio senses the electromagnetic environment, identifies the unused frequency bands in the spectrum, dynamically varies the radio operating parameters according to the availability of unused frequency band and then operates in those unused frequency bands where no activity by licensed user is detected. For further improving the spectral efficiency several DSA (Dynamic Spectrum Access) models have been proposed depending on the specificities of the environment. In the specific DSA context, the following definition proposed in [1] is one of the most cited ones: "Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment, and uses the methodology of understanding by building to learn from the environment and adapt its internal states to statistical variations in the incoming Radio Frequency (RF) stimuli by making corresponding changes in certain operating parameters (e.g., transmit power, carrier-frequency and modulation strategy) in real-time, with two primary objectives in mind:

- Highly reliable communication whenever and wherever needed
- Efficient utilization of the radio spectrum."

Several DSA models have been proposed to increase spectrum usage efficiency depending on the specificities of the environment. As described in Figure 1, DSA strategies can be in general classified into three different models [2]

Dynamic spectrum allocation approach used in this paper improves spectrum efficiency by dynamically assigning spectrum based on the spatial and temporal traffic statistics of different services. To implement this approach, the detected vacant frequency band is allocated to the OFDM standards employing unlicensed Secondary users which will re-configures its OFDM parameters according the available bandwidth. The aim of the research is to first sense the spectrum to find the vacant frequency bands and allocate the detected vacant frequency bands to the unlicensed user. In the second part, the research focuses on increasing the spectral efficiency. There are so many techniques available in the literature for spectrum sensing, each designed keeping in mind different requirements. Energy detection being one of them, it doesn't requires prior knowledge of the transmitting signal of the primary user. Thus making it most reliable and widely used. So for sensing the spectrum, Energy based detection technique is used and assuming the channel noise to be AWGN (Additive White Gaussian Noise).

Dynamic spectrum allocation approach used in the research improves spectrum efficiency by dynamically assigning spectrum based on the spatial and temporal traffic statistics of different services. To implement this approach, the detected vacant frequency band is allocated to the OFDM standards employing unlicensed Secondary users which will re-configures its OFDM parameters according the available bandwidth. Thus minimizing the difference between the available capacity and the capacity achieved by the unlicensed user to improve the spectral efficiency.

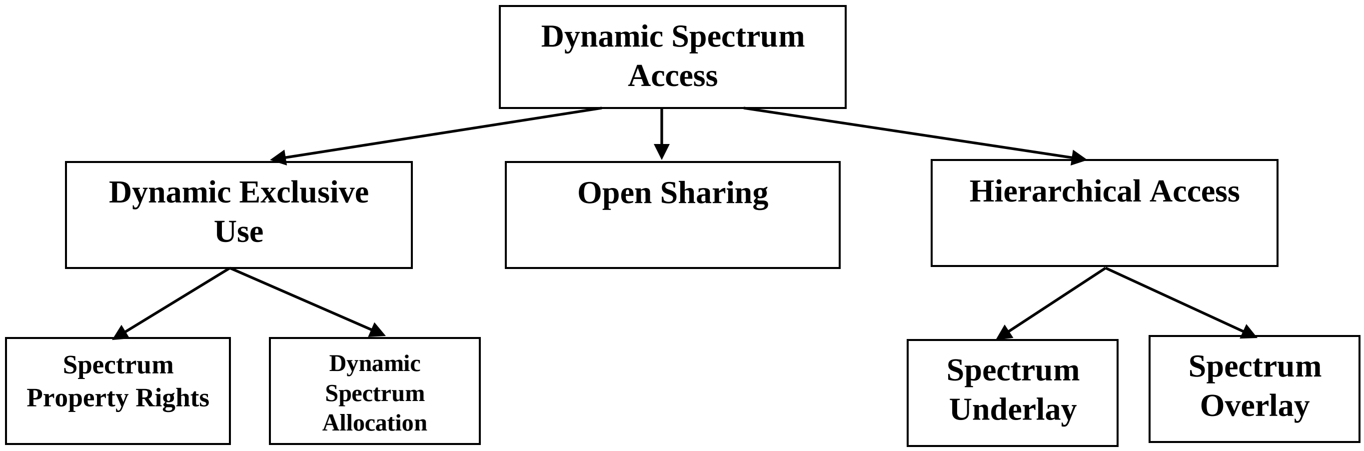

Figure 1 Classification of DSA Models

2. RELATED WORK

Many of researchers made their effort to efficiently utilize the spectrum by making the dynamic changes in operating parameters such as frequency, instantaneous bandwidth, modulation scheme, throughput, rate of transmission and transmission power level, so as to increase the system capacity of the Secondary user. By adjusting the system parameters of the Secondary user according to the allocated bandwidth, the CR system can improve overall Spectrum Capacity. [3]

In the literature, features of the Primary Users for implementing radio Resource Management are exploited. It then uses those features to classify the PU into different Clusters and defines a secondary user around that cluster which will adapt their parameters accordingly. Now the Problem with this scenario is that, if the SU does not finds the vacant band in the attached cluster for a very long time. Hence, remains in the waiting state for a long time. So this does not fully justifies the statement efficient use of available resources.

Now, Instead of extracting the features (bandwidth, allowed interference level, activity pattern) of Primary Users, which is rather a time consuming and difficult task, extract the bandwidth that is vacant in the spectrum and design the secondary users transmission parameters according to the available bandwidth.

The remainder of this paper is organized as follows: In Section 3 we present our proposed model. In Section 4, we have discussed results of the proposed Cognitive Radio system. In section 5, conclusion of the research is presented.

3. PROPOSED MODELLING

Spectrum efficiency can be significantly increased by giving the access of frequency bands not used by primary (licensed) users (PU) to a group of secondary (unlicensed) users (SU). Dynamic spectrum access (DSA) is the novel approach that enables flexible, efficient and reliable spectrum use by adapting the radios operating characteristics to the dynamically changing environments. A possible candidate for the implementation of DSA is Orthogonal Frequency Division Multiplexing (OFDM), a multicarrier modulation scheme which divides broadband channel into many orthogonal narrowband sub-channels.

Spectrum Sensing and Efficient Utilization of the Spectrum by reconfiguring the parameters of the OFDM based secondary users according the available spectrum environment are the most crucial tasks in cognitive radio based communication system. The algorithm proposed in this paper will help in increasing the Spectrum efficiency. The main idea behind the research is to minimize the difference between the available Capacity and the Capacity being used by the OFDM based Secondary users. By adjusting the system parameters of the OFDM based Secondary users, according to the allocated bandwidth; the Cognitive Radio system can maintain seamless communication. According to it, when there are few or less users, each user should be assigned a larger bandwidth for a higher data rate; when there are more users in communication range, the total spectrum should be divided to accommodate more simultaneous transmissions.

3.1. Spectrum Sensing

The Energy Detection Technique is used for spectrum sensing as this technique doesn't require the prior knowledge of the parameters of the primary user.

The hypothesis test for the signal identification can be expressed as

H1: x (n) = s (n) + w (n)

H0: x (n) = w (n)

Where, x(n) is Primary Signal,

w(n) is the AWGN (Additive White Gaussian Noise) noise

Hypothesis H0 represents the absence of primary user whereas H1 represents the presence of primary user.

The mathematical expression for the calculation of energy is given as:

$$\sum_{n=0}^{N} | x(n) |^2 \quad (1)$$

Estimating the power spectral density (PSD) based on discrete fourier transform (DFT).

$$X(k) = \sum_{n=1}^{N} x(n) \; e^{-j2\pi(k-1)(n-1)/N} \quad (2)$$

where $1 \leq k \leq N$

Where, x(n) is received Signal,

N is FFT size.

Then we apply X(k) to an energy detector as follows:

$$E = 1/N \sum_{k=1}^{N} |X(k)|^2 \quad (3)$$

This averaged energy E is then compared with the threshold λ to determine whether the primary signal is present or not.

3.2 Capacity Optimization

The main objective is to minimize the difference between the sum of the available capacities ($\sum C_{av}^{\,j}$) and the sum of the achievable OFDM based Secondary users data rates ($\sum R_k$), while assuring the interference protection toward the Primary users.

$$\text{Objective: min } \sum_{j=1}^{J} \sum_{k=0}^{K} C_{av}^{\,j} - R_k \quad (4)$$

$$R = \gamma\, B/N_k \sum_{n=1}^{N} \log_2 (1+ P\, |H|^2 / \Gamma\, N_{0*} (B/N_k)) \quad (5)$$

$$\gamma = T_{tx}/ (T_{tx} + T_s)$$

B is the available bandwidth for the OFDM based Secondary user

P is the Power allocated to the Secondary User. When in Idle state Secondary User transmits with maximum power P_{max}, when in busy state Secondary transmits and coexist with Primary User by varying its transmission power from P_{max} to $P_{s.}$

where $P_{max} > P_s$

$\Gamma = 1$ for idle state

$\Gamma > 1$ for Busy state

H is the Channel Gain

No is the Power Spectral Density

N_k is the Number of Subcarriers

Ts is the sensing time

T_{tx} is the Transmission Time for the secondary User

The maximum achievable value of Secondary Transmission time is set equal to the average PU idle time ($1/E[\phi^j(i)]$). [4][5][6]

In the VHF frequency band the available capacity can be calculate using the maximum available capacity formula:

$$C = B \log_2 (1+S/N) \quad (6)$$

B is the bandwidth which is used by the Primary User and at time free for the transmission of the Secondary user.

S/N is Signal to Noise ratio in the VHF frequency band. [7]

4. RESULTS AND DISCUSSIONS

For the simulation of the proposed technique in MATLAB, the spectrum band taken into consideration is VHF (Very High frequency) band from 54 MHz to 210 MHz. In the chosen frequency band a total of 10 Primary Users signals are being transmitted. 5 FM channels and 5 TV channels are transmitted as Primary Transmitter. The secondary users will be transmitting randomly generated 40000 data bits that could contain either web browsing data or data related to a file downloading. Maximum data transmission rate that could be achieved here is 70 Mbps.

The Primary users signal passed though the AWGN channel with Channel gain 0.5 and SNR - 10 dB, received at the Cognitive Radio Receiver is shown in Figure 2. The received signal is passed through Energy detector to detect the presence of the primary users signal. The Frequency bands in which there is only noise present are marked as ‘Holes’ and are available for the transmission of the Secondary Users Signals.

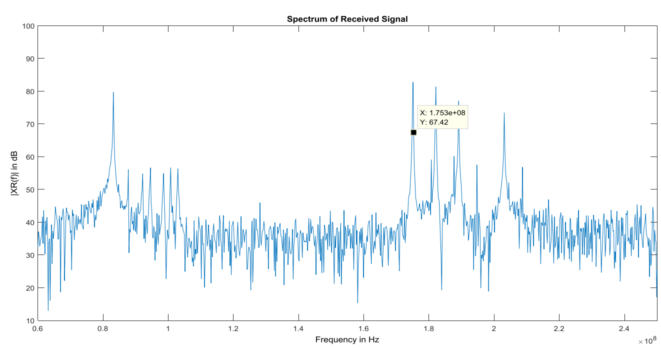

Figure 2 Spectrum of Received Signal at CR Receiver in MATLAB

To increase the Spectrum utilization OFDM based Secondary User's signals are transmitted in the detected vacant frequency bands. The power level of the Secondary Signal is kept low at 25mW so as to avoid causing any interference to the primary users signals and modulation techniques used are BPSK and QPSK, as we have assumed the channel condition is not very good, so if we use higher level of modulation the chances of data loss will be high. Initially, the Spectrum Utilization was only 29.5% in the frequency band under observation (54 MHz – 210 MHz). To further improve the spectrum utilization concept of OFDM based signals is introduced. OFDM gives the flexibility of selecting various bandwidth for the transmission of signals. Here the secondary users complies 802.16 WiMAX standard. It allows channel bandwidths to vary from 1.5 MHz to 20 MHz. It means as according to the availability of the bandwidth, the WiMAX based secondary user can adjust its parameters to achieve maximum utilization. The parameters that are adjusted in this research are FFT size, Number of total and data Subcarriers and Sampling Frequency. And hence the rate of transmission is changed.

The Comparison of the available Capacity in the vacant frequency band and the achievable capacity without implementing the concept of re-configuration of secondary signal and after implementing the concept of re-configuration of secondary signal to adapt in the available bandwidth for transmission is given in Figure 3 and Figure 4 respectively.

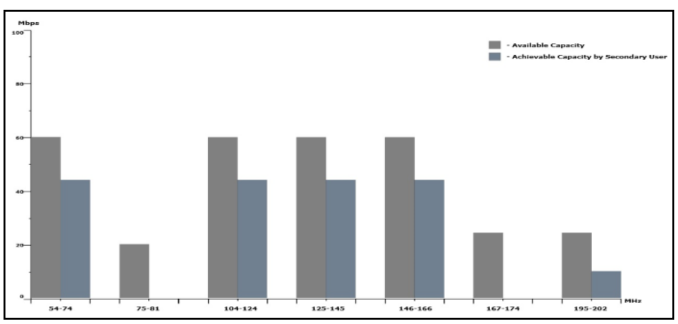

Figure 3 Comparison of available and achievable Capacity

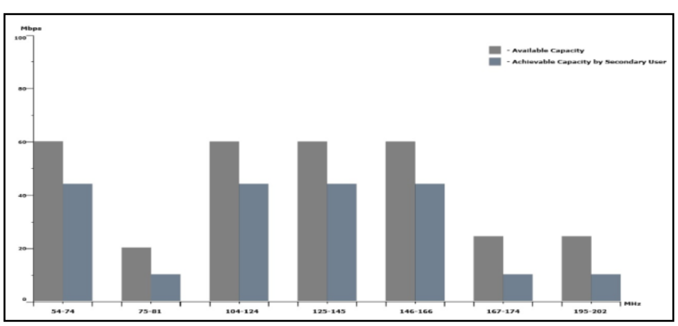

Figure 4 Comparison of available and achievable Capacity

The spectrum utilization has increased from 29.5% to 83% by transmitting the Secondary User in the Vacant Spectrum and it has further increased from 83% to 90% by using the re-configuration concept in 802.16 WiMAX signal in the spectrum region under observation. In the Figure 5 primary and secondary users signals after reconfiguration co-exist in the spectrum taken under observation to increase the overall spectrum utilization.

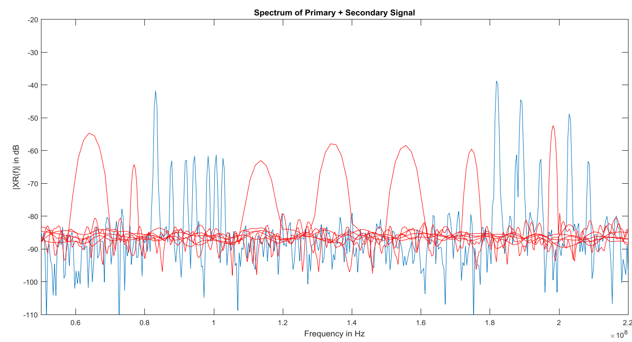

Figure 5 Spectrum of Primary and re-configured Secondary Users Signals in MATLAB

5. CONCLUSION

The transmission of unlicensed secondary users in the vacant frequency bands will improve the spectrum utilization. Now to further improve the spectral efficiency the unlicensed secondary users are designed according to IEEE 802.16 WiMAX standards. IEEE 802.16 WiMAX standard provides flexibility in choosing channel bandwidths ranged between 1.25 MHz and 20 MHz. The proposed objective is achieved by reconfiguring the OFDM parameters (FFT size, number of subcarriers used, sampling frequency and data rate) of the unlicensed secondary users (Designed in accordance with IEEE 802.16 WiMAX standards). The unlicensed secondary user will re-configure its parameter on-the-fly according to the available bandwidth so as to make maximum utilization of the available resources. Thus by allocating the vacant frequency bands to the IEEE 802.16 WiMAX standard employing secondary users the spectrum utilization has increased from 29.5% to 90% in the VHF frequency band taken under observation.

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