The 11th International Conference on Future Networks and Communications (FNC 2016)

Optimized Spectrum Selection through Instantaneous Channels Characteristics Evaluation in Cognitive Radio

LA Mpiana, KA Djouani, Y. Hamam

Department of Electrical Engineering, Tshwane University of Technology, Pretoria, South Africa
French South African Institute of Technology, Pretoria, South Africa

Abstract

The key idea to spectrum decision in Cognitive Radio Networks (CRN) is the selection of the best available spectrum band to satisfy Secondary Users (SUs) Quality of Service (QoS) requirements, without interfering with transmission of the licensed or Primary Users (PU). This challenging task requires a very good cooperation between users with different demands for the best use of spectrum channels of different characteristics in a heterogeneous network. In this paper we propose a linear optimization spectrum selection algorithm based on the evaluation of different channels characteristics and a linear optimization solution to ensure the selection of the best available spectrum satisfying the demands of the Secondary Users. The simulation results show that this approach ensures both the best transmission throughput and the transmission quality of service.

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Peer-review under responsibility of the Conference Program Chairs

Keywords: Cognitive Radio Networks, Primary User, Secondary User, Quality of Service, Linear Optimization, Spectrum Selection,

1. Introduction

The improvement of wireless communication over the past decade has increased the demand of the electromagnetic radio spectrum as societies become increasingly mobile and information technology dependent. In November 2002, the Federal Communications Commission (FCC) published a report prepared by the Spectrum-Policy Task Force, aimed at improving the way in which the radio spectrum is managed in the United States. In traditional wireless network, the radio spectrum is allocated to licensed users by the regulatory agencies and a scan portions of the radio spectrum allocated to licensed users,
reveals that some frequency bands in the spectrum are largely unoccupied most of the time or partially occupied while the remaining part are heavily used \(^2,^3\). Consequently, Dynamic Spectrum Access (DSA) techniques are proposed to solve the current spectrum inefficiency problems. In May 2004, the FCC followed up on its previous report and released its proposals dealing with the possible use of cognitive radio technology for low-power unlicensed devices to share spectrum in the very high frequency (VHF) and ultra high frequency (UHF) television bands \(^4\).

In his dissertation published in 1999 \(^5\), J. Mitola defined “Cognitive Radio” as a class of radio terminals that uses a real-time interaction with its environment to determine transmitter parameters such as power, frequency and modulation. From this definition, Cognitive radio contain two main functions \(^3,^6,^7\): The cognitive capability that refers to the ability of the radio technology to capture or sense variations in the radio environment using both autonomous learning and action decision and the Reconfigurability that enables the radio to be dynamically programmed according to the received information. For a good performance of the above functions, The Cognitive Radio Networks require the spectrum-aware operations, which form the cognitive cycle consisting of four spectrum management functions namely: Spectrum sensing, spectrum sharing, spectrum mobility and spectrum decision \(^3,^8\). The latter spectrum management function is very important although it has received little attention compared to other functions of cognitive radio network \(^9\). Different decision algorithm can be used to select the best available spectrum such as neural networks \(^10\), Fuzzy logic \(^11\), and game theory \(^12\). The main goal remains the selection of the optimized transmission channels responding to the dynamic changes of the wireless resources and ensuring a good quality of service.

N. Jain and Al. proposed a spectrum selection based on Signal-to-noise ratio \(^13\) and R. Prasad an Al. used probed packet delay as channel quality metrics to provide an estimation for channels quality \(^14\). Unfortunately those metrics do not accurately characterize channel contentions leading to high hit between primary users and secondary users. M. Kaplan and F. Buzluca \(^15\) developed a dynamic decision scheme utility function based on the parameters of the traffic class examining the effect of the user types in the decision making with different user categories while L. Marin and L. Giupponi \(^16\) developed a spectrum decision scheme for a cognitive ad-Hod Network based on the activity of the PUs and the maximum allowed interference. Although those methods provides an advantage on the estimation of the PUs activity of the spectrum, more instant transmission parameters need to be taken into consideration to ensure effective quality of service.

In our work, we present a linear optimization spectrum selection based on the instant spectrum characteristics including SNR, transmission power, and spectrum interference as registered in each targeting the maximum channel capacity with a better quality of service. This method allows the selection of the optimum spectrum by ensuring the inclusion of the above parameters as a set of variable and the evaluation of their effect in the quality of Service. The remainder of this paper is arranged as follows. Section II provides the functions of a spectrum decision scheme in CR network. Section III gives the details and the mathematics equations of the proposed spectrum selection scheme. Section IV give the simulation and the performance result. Section V concludes the paper.

2. Spectrum decision in Cognitive Radio

Cognitive radio networks require the capabilities to select the best spectrum band among the available bands according to the quality of service requirements. This notion called “Spectrum Decision” is very important in cognitive radio as it ensures better transmission performances. Spectrum decision is closely related to the channel characteristics and the operations of the Primary users and usually consists of three main functionalities \(^8\):
• Spectrum characterization: Based on the result of the spectrum sensing and the observations of the available spectrums, the CR user determines the characteristics of each available spectrum and the activity of the primary users. It is very important to understand that the set of characteristics of the channel will determine if the spectrum should be considered or not to achieve the required transmission needs.

• Spectrum selection: The CR user chooses his transmission band among the available spectrum bands. The user can select a transmission band without any information of its operating environment by applying a random channel selection policy. Though this process is low complex, it performs poorly particularly in the case of low spectral opportunities. Therefore the best available spectrum band is selected based on prior knowledge of the radio environment and the end-to-end route is determined.

• Reconfiguration: The CR users reconfigure the communication protocols and transmission parameters according to the radio environment and users QoS requirements. The cognitive radio can be programmed to transmit and receive on a variety of frequencies and use different transmission access technologies.

3. Channel characteristics based Spectrum Selection

The first step in Cognitive Radio Network is to find the spectrum holes unused by the primary users. Different methods such as matched filter, energy and feature detection are described to detect the available spectrum holes [6]. Spectrum sensing provides the information of the available spectrum holes to ensure an efficient secondary usage.

3.1 System model and assumptions

We consider a centralized cognitive radio network consisting of a primary user and secondary user with a number n of transmission channels that can be used by a secondary user if not being used by the primary user. The set of channels can be represented by \(A = \{C_1, C_2, C_3, \ldots, C_n\}\). \(C_i\) is the channel capacity of a specified spectrum \(i\). Each spectrum \(i\) is characterized by its Signal to Noise Ratio (SNR), the transmission power, the interference level and the available bandwidth. Those parameters are selected because of their dependence either to the channel capacity or quality of service. A channel can be selected to for transmission if it provides a better transmission throughout under low transmission power, low interference and bigger transmission bandwidth.

Each channel can be modelled as two state processes: one state representing the activity times and the other as inactivity times, referred to as busy and idle states respectively. Therefore first step in the cognitive radio has said early is to find the spectrum holes. We will call Binarization of the spectrum the result of the spectrum sensing identifying a spectrum as being used by a primary user or not.

In the binarization process a spectrum hole is identified as “1” if the spectrum hole is available and can be utilized by the secondary user and as “0” if the spectrum is occupied by the Primary users or other secondary users.

3.2 Channels characteristics Evaluation

Although the scanning of spectrum holes can reveal the result of the activities of the spectrum, different spectrum holes that might be available at a time, may not have the same transmission characteristics, hence the Cognitive Radio Capacity \(C_i\) (k), the expected normalized capacity of user \(k\) in spectrum \(i\) is different from one spectrum to another \(^{17}\). A set of characteristics of an available spectrum will be evaluated by the spectrum management to ensure the selection of the best available spectrum.

A linear optimization function ensuring the selection of the best available spectrum bands, constraint to the spectrum characteristics can be formulated as:

Maximize \(\sum_{i\in A} \frac{C_i^{CR}(k)}{\beta} x_i\)  \quad (1)

Subject to:
\[\sum_{i\in A} x_i = N\]
\[\sum_{i\in A} x_i \cdot C_i \geq \sum_{i\in A} x_i \cdot C_{i-1}\]
\[\sum_{i\in A} x_i \cdot P_i \leq P_{max}\]
\[\sum_{i\in A} x_i \cdot I_i \leq I_{max}\]
With $C_i^{CR}$ the channel capacity of the available spectrum holes with respect to the Shannon transmission capacity, $x_i$ is the selected spectrum from the set of available spectrum bands, $\beta$ is the user requirement and $N$ transceivers of the cognitive radio user, $P_i$ and $I_i$ are power and the interference level in a selected spectrum $i$ respectively. $P_{max}$ and $I_{max}$ are the maximum transmission power and interference respectively. The channel capacity is calculated using the Shannon formula based on the Bandwidth ($B$) and the signal to noise ratio of the spectrum as follow:

$$C_i = B \log_2 (1 + SNR_i)$$  \hspace{1cm} (2)

This is to ensure the efficient spectrum responding to the secondary user need with a low level of noise.

The interference signal at the primary receiver generated by the $i^{th}$ cognitive interferer is modelled using a statistical model for per dimension aggregate interference of a CRN

$$I_i = \sqrt{P_i R^{-b} n_i}$$  \hspace{1cm} (3)

Where $P_i$ is the interference signal power at the limit of the near-far region (which limited to 1 meter), $R$ is the distance between the $i^{th}$ cognitive interferer and the primary receiver, $b$ is the amplitude path-loss exponent, and $n_i$ is the per-dimension fading channel path gain of the channel from the $i^{th}$ cognitive interferer to the primary receiver.

Therefore, the proposed simplex optimization spectrum decision framework focuses on the spectrum selection based on the result of the binarization of the spectrum and the characteristics of the spectrum, the bandwidth, the interference level, the required transmission power and the required capacity to respond to the secondary user need.

The objective function of the optimization problem can calculated and derived from equation (1):

$$a_1 x_1 + a_2 x_2 + \cdots a_m x_m$$  \hspace{1cm} (4)

With $a_1, a_2 \ldots a_m$: the coefficients of each spectrum calculated using the Shannon channel capacity formula.

We determine the basics variables based on the available spectrum as result of the spectrum binarization and the slack variables based on the quality of service constraints.

The basic variable $X_b = \begin{bmatrix} x_1 \\ \vdots \\ \vdots \\ x_n \end{bmatrix}$

The basic matrix $B = \begin{bmatrix} B_{11} & \cdots & B_{1n} \\ \vdots & \ddots & \vdots \\ B_{n1} & \cdots & B_{nn} \end{bmatrix}$

$$B^* X_b = b$$  \hspace{1cm} (7)

With $b$ the maximum values of the transmission matrix.

### 4. Simulation and Numerical Result

The efficiency and benefits of the proposed model was studied using numerical examples computed in MATLAB. MATLAB allows matrix manipulations and linear programming implementation of the revised simplex methods to ensure the optimum selection of the best available spectrums. We have assumed a CRN with a maximum of 8 spectrum holes that can be opportunistic detected at a specific period of time by the secondary user. The Spectrum Management Center (SMC) is able to communicate with secondary user and exchange the characteristics of the available spectrum for an efficient selection.

The spectrum sensing gives the following spectrum binarization result: $[0 \ 1 \ 1 \ 0 \ 0 \ 1 \ 1 \ 0]$. The secondary user can select his transmission spectrum only among the available spectrum.

In this paper the Best Spectrum Channel concept is extended to the spectrum that can fulfil the user needs with a good quality of service compare to others.
The Table 1 below summarizes a set of spectrum with their characteristics used during our simulations for each spectrum allocated to the secondary user with Bw the bandwidth (MHz) of the spectrum, SNR (dB) is the signal to noise ratio of each spectrum at a specific period of time, Power (dBm) is the required transmission power and INT (dB) is the interference level of the spectrum.

Table 1: Spectrum characteristics

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>Bw (MHz)</th>
<th>SNR (dB)</th>
<th>Power (dBm)</th>
<th>INT (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>8</td>
<td>38</td>
<td>2.76</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>14</td>
<td>33</td>
<td>2.15</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>14</td>
<td>32</td>
<td>3.92</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>10</td>
<td>38</td>
<td>3.75</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>13</td>
<td>32</td>
<td>5.58</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>12</td>
<td>29</td>
<td>2.42</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>13</td>
<td>28</td>
<td>4.79</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
<td>11</td>
<td>35</td>
<td>4.77</td>
</tr>
</tbody>
</table>

Using the above Shannon formula of the channel capacity, from the above table we obtain:

\[ C = \log_2 (1 + \text{SNR}) \]

After spectrum sensing with the following binarization code: [0 1 1 0 0 1 1 0]. and with \( \beta \) equal to 150 with 2 transreceivers, the objective function becomes:

Maximise \( 0.78x_2 + 0.47x_3 + 0.55x_6 + 0.59x_7 \)

Subject to

\[ x_2 + x_3 + x_6 + x_7 + \leq 2 \]
\[ 2x_2 + 1.6x_3 + 0.8x_6 + 0.63x_7 \leq 5 \]
\[ 2x_2 + 3.9x_3 + 2.4x_6 + 4.8x_7 \leq 10 \]
\[ x_2, x_3, x_6, x_7 \geq 0 \]

Figure 1. b indicates that some spectrum holes are not available as consequence of the spectrum sensing while they are in use by the primary user. After the evaluation based on the channel characteristics using the simplex methods, an optimum solution is reached and two spectrums can be selected: [0 1 0 0 1 0 0] with the spectrum \( x_2 \) being the most suitable spectrum.

From the below results, we can see that the secondary user can select spectrum 2 and 6 for his transmission with spectrum 2 having the most desirable transmission quality with a very good channel capacity and signal to noise ratio.
5. Conclusion

In this paper, a spectrum selection algorithm based on channels characteristics is proposed. The goal is to achieve a selection of the best available spectrum by evaluating the channel characteristics responding to the secondary user needs. This is achieved by an effective collaboration of the spectrum management and the secondary user to match the user requirements. In the current paper, we have worked more on constant parameters to determine the quality of service for the spectrum selection. The future work will include the implementation of the proposed algorithm using simulation tools such as OPNET or ns-3 where the cost of the physical implementation will be studied. The spectrum reconfiguration as part of spectrum decision for the the best available spectrum will also be studied to complete this work.

6. References