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Application of combined TOPSIS and AHP method for Spectrum Selection in Cognitive Radio by Channel Characteristic Evaluation

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Abstract

The key idea to spectrum decision in Cognitive Radio Networks (CRN) is the selection of the best available spectrum band to satisfy the Quality of Service (QoS) requirements of Secondary Users (SUs), 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 combination of the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Analytic Hierarchy Process (AHP) optimization spectrum selection algorithms based on the evaluation of different channels characteristics and an optimized solution to ensure the selection of the best available spectrum satisfying the demands of the secondary users. Some of the advantages of TOPSIS method are: simplicity, rationality, comprehensibility, good computational efficiency and ability to measure the relative performance for each alternative in a simple mathematical form. The analytical results show that this approach ensures the best transmission quality of service with simplified method.

AMS subject classification:
Keywords: TOPSIS method, AHP method, Cognitive Radio Networks, Optimization, Multi Criteria Decision Making.

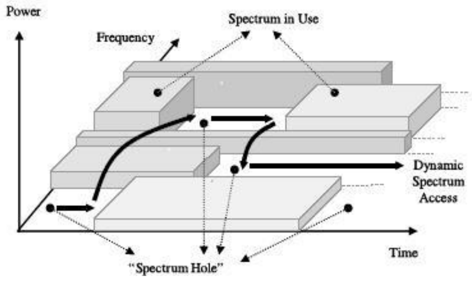

Figure 1: Illustration of spectrum white space [2]

1. INTRODUCTION

The need for higher data rates is increasing because of the transition from voice-only communications to multimedia type applications. With the limitations of the natural frequency spectrum, it becomes obvious that the current static frequency allocation schemes cannot accommodate the requirements of an increasing number of higher data rate devices [1]. Figure 1 shows relatively low utilization of the licensed spectrum which is largely due to inefficient fixed frequency allocations rather than any physical shortage of spectrum. As a result, innovative techniques that can offer new ways of exploiting the available spectrum are needed. Cognitive Radio (CR) is an intelligent wireless communication system that is cognizant of its environment, learns from it and adapts its transmission features according to statistical variations in the environment to maximize utilization of premium resources such as spectrum while ensuring good Quality of Service (QoS).

Cognitive radio includes four main Spectrum management functional blocks: spectrum sensing, spectrum sharing, and spectrum mobility and spectrum decision [3] [4]. Spectrum sensing aims to determine which spectrum is available and to detect the presence of the licensed users (also known as a primary user) when a user operates in a licensed band. Spectrum sharing is to distribute the spectrum holes fairly among the secondary users, bearing in mind usage costs. Spectrum mobility is to maintain seamless communication requirements during the transition to better spectrum.

The spectrum decision function [5] is responsible for selecting the most appropriate spectrum for opportunistic usage and to avoid interference to PUs (Primary Users) by using the information it receives from spectrum sensing function. When selecting a spectrum band for SUs (Secondary Users), the spectrum decision function selects a spectrum band based on SUs' Quality of Service (QoS) requirements, such as bandwidth, PU utilization level, and channel quality. The spectrum decision function avoids interference to PUs by either waiting for PU activity to cease or switching to another available spectrum band. In order to switch to another spectrum band, the spectrum hand- off function is invoked [5]. Even though TOPSIS is more reliable while dealing with different attributes and in the assessment of number of alternatives, it needs an appropriate procedure to determine the weight criteria of each objective. AHP method has been used to assign the weight of each criterion. AHP provides an effective structured technique based on mathematical concept. In this work AHP is applied to find the weight of each criterion. Hence advantages of TOPSIS and AHP methods are combined to find the optimized spectrum based on the instant spectrum characteristics including Bandwidth (BW), Signal to Noise Ratio (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 attribute and the evaluation of their effect in the quality of Service.

The remainder of this paper is arranged as follows. Section II discusses multiple attributes decision making (MADM) methods and the mathematical equations of the proposed optimization scheme for spectrum selection. Section III gives spectrum selection based on channel characteristics with system model. Section IV gives Numerical results and section V concludes the paper.

2. MULTIPLE ATTRIBUTES DECISION MAKING METHODS

MADM methods [6] [7] are mathematical methods of decision making with decision problems in the presence of a number of decision attributes. MADM methods are used to select an appropriate alternative from a finite number of alternatives. The alternative is selected based on the information of each attribute with respect to each alternative. The results are known to be effected by several factors. An MADM method specify how attribute value is processed in order to arrive at a choice. There are several MADM methods such as SAW, AHP, and TOPSIS etc. MADM methods can be used for optimized spectrum selection in CR networks. It deals with selecting optimal spectrum from a number of PU spectrums and QoS with respect to different attributes.

2.1. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is a multi-criteria method developed by Yoon and Hwang [8] to identify solutions from finite set of alternatives. Multi criteria decision making (MCDM) method are the multi objective optimization techniques that has been used to evaluate the alternatives. The objectives with the highest relative closeness to the positive solution are suggested for optimal combination of input parameters. The basic principle is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. In recent years, TOPSIS has been successfully adopted in various fields of Communication.

The procedure of TOPSIS can be expressed in a series of following steps [9]

Step 1: Calculate the normalized decision matrix. The normalized value n_{ij} is calculated as:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum\limits_{j=1}^{m} x_{ij}^2}} \tag{1}$$

Step 2: Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = w_i * n_{ij}, j = 1, \ldots, m, i = 1, \ldots, n \tag{2}$$

Where Ï‰$_i$ is the weight of the ith attribute or criterion, and $\sum_{i=1}^{n} = 1$

Step 3: Determine the positive ideal and negative ideal solution

$$A^+ = \{v_1^+, ...v_n^+\} = \{(max_j * v_{ij} \mid i \in I), (min_j * v_{ij} \mid i \in J)\} \tag{3}$$

$$A^- = \{v_1^-, ...v_n^-\} = \{(max_j * v_{ij} \mid i \in I), (min_j * v_{ij} \mid i \in J)\} \tag{4}$$

Where I is associated with benefit criteria and J is associated with cost criteria.

Step 4: Calculate the separation measure using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as:

$$d_j^+ = \sqrt{\left\{\sum_{i=1}^{n} \left(v_{ij} - v_i^+\right)\right\}}, j = 1, \ldots, m \tag{5}$$

$$d_j^- = \sqrt{\left\{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)\right\}}, j = 1, \ldots, m \tag{6}$$

Step 5: Calculate the relative closeness to the ideal solution. The relative closeness of the alternative A_j with respect to A+ is defined as:

$$R_j = d_j^- / (d_j^+ + d_j^-), j = 1, \ldots, m \tag{7}$$

Since $d_j^- \geq 0$ and $d_j^+ \geq 0$, then clearly $R_j \in [0, 1]$.

2.2. Analytic Hierarchy Process (AHP)

Thomas Saaty developed AHP in the 1970s as a way of dealing with weapons tradeoffs, resource, asset allocation and decision making. AHP is a decision-making tool that can help describe the general decision operation by decomposing a complex problem into a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives [10]. AHP can be used in making decisions that are complex, unstructured, and contain multiple attributes [11]. AHP provides a method to connect that can quantify the subjective judgment of the decision maker in a way that can be measured. AHP is a method of breaking down a complex, unstructured situation into its components parts, arranging these parts or judgments on the relative importance of each variable, and synthesizing the judgments to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation [12] [10]. Saaty allowed some measures

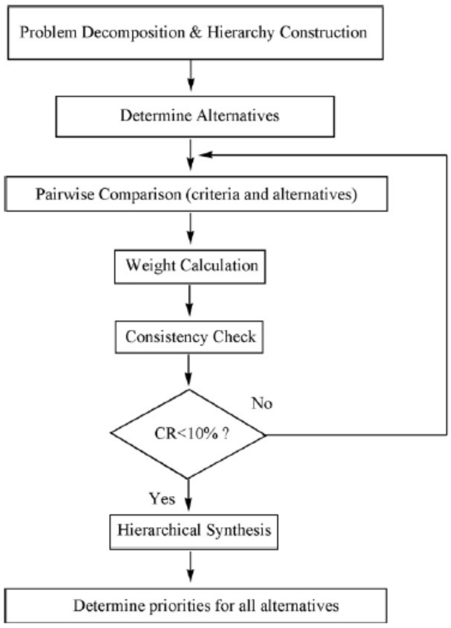

Figure 2: Schematic representation of the AHP method

of inconsistency (common with subjective human judgment) when applied to the logic of preferences. Inconsistencies arise when comparing three items, A, B, and C. For example, if item A is more preferred over item B, and item B is more preferred over item C, then by the transitive property, Item A should be more preferred over item C. If not, then the comparisons are not consistent. AHP uses derived weights that show the importance of various criteria. AHP allow for individual attribute preferences or inconsistency measures. AHP consists of four steps. One, define the problem and state the goal or objective. Two, define the criteria or factors that influence the goal. Structure these factors into levels and sublevels. Three, use paired comparisons of each factor with respect to each other that forms a comparison matrix with calculated weights, ranked eigenvalues, and consistency measures. Four, synthesize the ranks of alternatives until the final choice is made. The schematic representation of AHP is shown in Fig. 2.

3. SPECTRUM SELECTION BASED ON CHANNEL CHARACTERISTIC

Uniqueness of cognitive radio is its ability to sense the environment over the huge spectrum and adapt to it. So it is necessary to dynamically detect the existence of signals of primary users. There have been several sensing algorithms, including the energy detection, matched filtering, Cyclostationary feature detection and Eigen value based detection. [13] Spectrum sensing provides the information of the available spectrum holes to ensure an efficient secondary usage [14].

Table 1: Spectrum Characteristics matrix [15]

Spectrum	BW (MHz)	SNR (dB)	Pw (dBm)	INT (dB)
1	20	8	38	2.76
2	25	14	33	2.15
3	15	14	32	3.92
4	25	10	38	3.75
5	20	13	32	5.58
6	20	12	29	2.42
7	20	13	28	4.79
8	25	11	35	4.77

3.1. System Model

We consider a cognitive radio network consisting of a primary user and secondary user with n number of transmission channels that can be used by a secondary user if not being used by the primary user. Each spectrum i is characterized by its Signal to Noise Ratio (SNR), the available bandwidth, the transmission power and the interference level. 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 higher transmission bandwidth, higher signal to noise ratio, low transmission power and low interference. First step in the cognitive radio is spectrum sensing to find the spectrum holes. one state representing the activity times and the other as inactivity times, referred to as busy and idle states respectively. In the binarization process a spectrum hole is identified as 1ž if the spectrum hole is available and can be utilized by the secondary user and as 0ž if the spectrum is occupied by the Primary users or other secondary users [15]. A set of characteristics of an available spectrum will be evaluated by the spectrum management to ensure the selection of the best available spectrum. Combination of TOPSIS and AHP is used to select the best available spectrum for secondary user.

4. NUMERICAL RESULTS

We have assumed a Cognitive Radio Network with a maximum of 8 spectrum holes that can be opportunistically 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].

Table 1 gives six spectrum characteristics for simulation purpose in terms of available Bandwidth (BW) in MHz, Signal to noise ratio (SNR) in dB, transmission power (Pw) in dBm and interference (INT) in dB.

Calculated weights by AHP method are 0.5361, 0.2681, 0.1787 and 0.1340 for BW, SNR, Pw and INT respectively.

Table 2: Normalized matrix for spectrum Characteristics

Spectrum	BW (MHz)	SNR (dB)	Pw (dBm)	INT (dB)
1	0.3288	0.2350	0.4034	0.2475
2	0.4110	0.4112	0.3503	0.1928
3	0.2466	0.4112	0.3397	0.3515
4	0.4110	0.2937	0.4034	0.3363
5	0.3288	0.3819	0.3397	0.5004
6	0.3288	0.3525	0.3078	0.2170
7	0.3288	0.3819	0.2972	0.4295
8	0.4110	0.3231	0.3715	0.4277

Table 3: Weighted Normalized matrix

Spectrum	BW (MHz)	SNR (dB)	Pw (dBm)	INT (dB)
1	0.1763	0.0630	0.0721	0.0332
2	0.2203	0.1103	0.0626	0.0258
3	0.1322	0.1103	0.0607	0.0471
4	0.2203	0.0788	0.0721	0.0451
5	0.1763	0.1024	0.0607	0.0671
6	0.1763	0.0945	0.0550	0.0291
7	0.1763	0.1024	0.0531	0.0576
8	0.2203	0.0866	0.0664	0.0573

Table 4: Separation measure of positive, negative ideal solutions and relative closeness value

Sr.No.	S**	S*	Relative closeness (C*)	Rank
1	0.0678	0.0556	0.4508	7
2	0.0095	0.1086	0.9196	1
3	0.0910	0.0526	0.3662	8
4	0.0416	0.0922	0.6893	2
5	0.0613	0.0602	0.4953	6
6	0.0469	0.0684	0.5929	4
7	0.0549	0.0628	0.5337	5
8	0.0416	0.0919	0.6885	3

Where S** is Separation measure of positive ideal solution and
S* is Separation measure of negative ideal solution

4.1. Priority and Result

With TOPSIS method, relative closeness values are 0.4508,0.9196,0.3662, 0.6893, 0.4953, 0.5929, 0.5337 and 0.6885 for 1 to 8 spectrums respectively. From these priority values

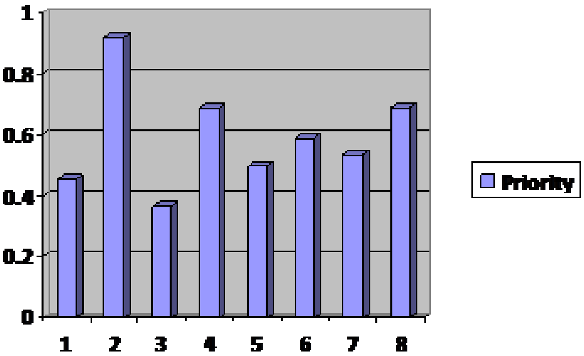

Figure 3: Spectrum priority result

and as shown in Fig. 3, ranking of spectrums for secondary users is 2-4-8-6-7-5-1-3. From the above results, we can see that the secondary user can select spectrum 2 and 4 for his transmission with spectrum 2 having the most desirable transmission quality with a very good available bandwidth and signal to noise ratio.

5. CONCLUSION

In this paper, a simplified spectrum selection algorithm based of channel characteristics is proposed. The goal is to achieve a selection of the best available spectrum by evaluating the channel characteristics as per the secondary user needs. This is achieved by an effective collaboration of the spectrum management and the secondary user to match the user requirements by combined TOPSIS and AHP method. The algorithm presented above illustrated how multiple criteria can be included in the TOPSIS approach to allow flexible and inclusive use of data for spectrum selection decision. The TOPSIS methodology can select the best spectrum to satisfy secondary user's need. In this paper, constant parameters are used to determine the quality of service for the spectrum selection. The future work will include the spectrum sensing using energy detection technique to identify the spectrum holes and then spectrum decision using other MADM techniques.

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