Intelligent algorithm for spectrum mobility in cognitive wireless networks
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Abstract

Currently the growing demand for wireless communications users has generated the study and implementation of cognitive wireless networks. To find a channel with the required characteristics for the continuous communication of the secondary users is essential for spectral mobility, in cognitive wireless networks. This paper presents a fuzzy algorithm for the spectrum decision function and in particular for the selection of a backup channel in spectral mobility. The proposed fuzzy algorithm is based on decision-making multiple criteria. This paper proposes a benchmarking of performance of the two spectrum handoff models: Analytical Hierarchical Process and the proposed Fuzzy Algorithm. The metric evaluations used are an accumulative average of failed handoffs, accumulative average of performed handoffs and, average of transmission bandwidth. The proposed algorithm provides an effective frequency channel selection. The results show a reduction of the rate of channel changes in contrast to the AHP selection method.

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Keywords: fuzzy logic; spectrum handoff; cognitive wireless networks; spectral frequency;

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1. Introduction

THE cognitive radio is a technique that provides the capability for the unlicensed user or the secondary user (SU) to use or share the spectrum in an opportunistic manner from the auto-coexistence with the licensed user or primary user (PU), changing the transmission parameters allowing to operate in the best available channel depending on environment behavior. The RC should determine which spectrum part does not have licensed users who are using it (detection of the spectrum). The cognitive radio can increase the spectral efficiency, because it allows SU to share opportunistically the spectrum with PU\(^1\).

In cognitive radio, the spectrum handoff can be defined as the process whereby a SU changes its operating frequency. The main problem in a change of frequency is the time it takes to find a new channel available, and depending on the type of information that is being transmitted this may not be tolerable. The use of algorithms to avoid signal degradation and provide a time of satisfactory duration within the licensed bands are big challenges.

If the selection of the channel is defective, then the transmission may be paused because a channel may change for various reasons such as, it is about to be occupied by a PU or it is already occupied and, when the channel presents low quality. The multiple channel changes induced by the poor channel selection causes a significant increase in the delay that directly affects the performance and quality of service for the SU communication\(^2\).

Therefore, to find a channel with the required characteristics for the continuous communication of the SU, it is essential for spectral mobility\(^3\).

The selection of the criteria is a fundamental task for proactive evaluation of the availability and optimal conditions to select a backup channel. Therefore, it is found in related documents that once the selection criteria are established, the development of the multiple criteria decision making (MCDM) methodology is widely used. This MCDM method is based on two processes, the weights assessment of each criterion using the AHP\(^4\), and the ranking estimation of each possible solution by means of one of the following techniques, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the Simple Additive Weighting (SAW), the Multiplicative Exponent Weighting (MEW) or the Grey Relational Analysis (GRA)\(^5-10\).

This paper presents a fuzzy algorithm for the spectrum decision function and in particular for the selection of a backup channel for spectral mobility. The proposed fuzzy algorithm is a MCDM technique that has proven to be an effective method for the selection of backup channel alternatives. This algorithm is a hybrid between Analytical Hierarchical Process (AHP) Algorithm\(^4\) complemented with fuzzy logic, it improves the management of subjectivity and reduces uncertainty in the information and, also improves the criteria assessment.

The backup channel is a channel that has been previously selected based on rules and predefined criteria. This allows to the SU to change channel with a short delay because it is not necessary to wait until the spectrum detection and until the decision of the spectrum is taken\(^1, 11, 12\).

The rest of the document is structured as follows. In Section II, the development of the FAHP Algorithm is explained. In Section III, the results of the developed algorithm are shown and in Section IV, the conclusions are presented.

2. Fuzzy Algorithm

The AHP Method is an estimation algorithm for multi-criteria decision making including quantitative and qualitative criteria. This allows the AHP Algorithm to evaluate different variables when selecting a single choice within a wide set of possible alternatives. This is based on subjective judgments, by contrasting the significance of the criteria used for the selection of diverse alternatives. As a consequence, this being a relative measure rather than an absolute assessment\(^13\). However, the AHP Satty method\(^13\) has some limitations for instance, (1) it works with an unbalanced scale of judgments, (2) it cannot handle uncertainty and ambiguity in the information associated to the assigned number of each assessment, (3) the ranking of AHP is rather vague, (4) the subjectivity of the judgment where the selection and preference of decision makers have significant influence on the results. These limitations can be mitigated by the integration of the fuzzy logic to AHP Algorithm\(^9, 14\).

Fuzzy logic is an appropriate tool to make decisions in situations where the available inputs are uncertain and imprecise or qualitatively interpreted. Fuzzy logic can also transform qualitative and heterogeneous information in homogeneous membership values, which these can be processed by a set of appropriate rules of fuzzy inference\(^15\).
The proposed Fuzzy Algorithm was developed with four steps: (1) problem definition, (2) construction of the hierarchy, (3) construction of the matrix of judgments, and (4) calculation of the normalized weights.

The problem is defined and classified as follows, the objective, the criteria and the alternatives. The objective is the decision making to be taken, and thus, for the current work corresponds to the selection of the best option for an available backup channel in cognitive wireless networks. The criteria are the factors affecting the preference of the alternatives. After the analysis of the variables that can affect or influence the process of spectral CR mobility, this work considered only four variables of interest for the proposed multi-criteria decision algorithm because of the relevance and because they are enough to assess the channel conditions: availability probability of channel (AP), estimated channel time availability (ETA) and the Signal to interference plus noise ratio of channel (SINR) and bandwidth of the channel (BW).

The selected criteria were obtained using only experimental data. It was decided to work with Wi-Fi channels corresponding to the frequency band of 2.4 GHz to 2.5 GHz. The reason for choosing selecting this set of alternatives is based on the high demand for Wi-Fi Networks and the easy spectral detection by using the "energy detection" technique.

Based on the objective, the criteria and the alternatives; the hierarchy structure is constructed to develop the design methodology of the Fuzzy Algorithm proposed.

Once the hierarchy structure is built, the judgment matrices are constructed in agreement with the AHP Method. These matrices correspond to the comparative benchmarks that define the relative significance between possible combinations of pairs of criteria. For the analysis of the alternatives, it is considered that the frequency channels change dynamically their characteristics in time. Then, the Fuzzy Algorithm evaluates dynamically the alternatives.

The fuzzy importance scale (see Table 1) is obtained by the conversion of nine levels of the fundamental importance scale, to a fuzzy numbers presented by Büyüközkan. Based on the fuzzy importance scale presented in Table 1, the level of relative significance of each pair of criteria was determined and the judgment matrix of the criteria were constructed (see Table 2). The diagonal of each matrix corresponds to the equality, since it compares the importance of the criteria with themselves. The upper half from the diagonal of the matrix describes the relative importance of the criteria of the first column with respect to the criteria of the first row.

Table 1. Scale of importance.

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Importance Scale</th>
<th>Fuzzy Triangular Scale</th>
<th>Fuzzy Triangular Scale Reciprocal</th>
</tr>
</thead>
<tbody>
<tr>
<td>EI</td>
<td>Equal importance</td>
<td>(1/2, 1, 3/2)</td>
<td>(2/3, 1, 2)</td>
</tr>
<tr>
<td>MI</td>
<td>Moderate Importance</td>
<td>(1, 3/2, 2)</td>
<td>(1/2, 2/3, 1)</td>
</tr>
<tr>
<td>SI</td>
<td>Strong Importance</td>
<td>(3/2, 2, 5/2)</td>
<td>(2/5, 1/2, 2/3)</td>
</tr>
<tr>
<td>VSI</td>
<td>Very strong importance</td>
<td>(2, 5/2, 3)</td>
<td>(1/3, 2/5, 1/2)</td>
</tr>
<tr>
<td>XI</td>
<td>Extreme importance</td>
<td>(5/2, 3, 7/2)</td>
<td>(2/7, 1/3, 2/5)</td>
</tr>
</tbody>
</table>

Table 2. Judgment matrix for the criteria.

<table>
<thead>
<tr>
<th>Sub-criteria</th>
<th>AP</th>
<th>ETA</th>
<th>SINR</th>
<th>BW</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>(1/2, 1, 3/2)</td>
<td>(1, 3/2, 2)</td>
<td>(3/2, 2, 5/2)</td>
<td>(3/2, 2, 5/2)</td>
</tr>
<tr>
<td>ETA</td>
<td>(1/2, 2/3, 1)</td>
<td>(1/2, 1, 3/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>(3/2, 2, 5/2)</td>
</tr>
<tr>
<td>SINR</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(1/2, 1, 3/2)</td>
<td>(1/2, 2/3)</td>
</tr>
<tr>
<td>BW</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(1/2, 2/3, 1)</td>
<td>(1/2, 1, 3/2)</td>
</tr>
</tbody>
</table>

With the judgments matrices already defined, the normalized weights were calculated for each criteria, based on the proposed model. These results are based on the fuzzy extended analysis presented. The results from the weight vector corresponding to the criteria are shown in Table 3.
Table 3. Normalized weights of the RT sub-criteria\textsuperscript{16}

<table>
<thead>
<tr>
<th>Criteria</th>
<th>AP</th>
<th>ETA</th>
<th>SINR</th>
<th>BW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.3593</td>
<td>0.2966</td>
<td>0.1970</td>
<td>0.1471</td>
</tr>
</tbody>
</table>

The normalized weights describe the relative degree of importance of each criteria to select the backup channel. Then, the channel selection depends on approximately, 36% AP, 30% for the ETA, 20% for the SINR, and 14% for the BW. With this weight, all available frequency channels are evaluated, which it corresponds to the alternatives in the hierarchy of the developed Fuzzy Algorithm. The channels are classified from the highest to the lowest evaluated scores and, with the highest channel score resulting as the backup channel\textsuperscript{16}.

3. Results

The evaluation of the developed Fuzzy Algorithm was performed using real experimental data of the spectrum occupancy measured in a Wi-Fi network. This process was carried out in order to accurately assess the performance of the algorithm and validate the algorithm performance with applicable experimental data. A simulation environment progressively reconstructs the actual behavior of the spectral occupancy through traces of captured data in the Wi-Fi frequency band. This allows to model, without any mistakes, the behavior of the PUs and accurate assess and validate the performance of each spectral handoff. The spectral occupancy data corresponds to a trace of 10 minutes of traffic.

The validation of the proposed Fuzzy Algorithm was performed through the comparison with the algorithm AHP, through three evaluation metrics. (1) Accumulative average number of failed handoffs (Fig. 1A, 1B), (2) Accumulative average number of handoffs (Fig. 2A, 2B) and, (3) Accumulative average of transmission bandwidth (Fig. 3A, 3B). After running several periods of simulation for each spectrum handoff, the average values of the three metrics are calculated and the comparative analysis is performed.

![Fig. 1. Accumulative average number of failed handoffs a) for Fuzzy Algorithm b) for AHP](image1)

![Fig. 2. Accumulative average number of handoffs a) for Fuzzy Algorithm b) for AHP](image2)
4. Conclusions

This paper presents a validation with experimental data captured from the Wi-Fi frequency band. Therefore, this simulation models a realistic environment which describes the actual behavior of the licensed users.

The developed Fuzzy Algorithm based on multiple-criteria decision making is an instrument for decision-making that improves efficiency for the selection of spectrum opportunities.

According to the results of the developed Fuzzy Algorithm, a reduction of the rate of channel changes is shown in comparison with AHP Algorithm.

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