International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 14, Number 8 (2021), pp. 822-828
© International Research Publication House. http://www.irphouse.com

AHP-COPRAS SPECTRAL MOBILITY MODEL

Jhonatan E. Martínez[1], **Jhon J. Abreo**[2] **and Cesar Hernández**[3]
[1,2] Ing. Students, Universidad Distrital Francisco José de Caldas, Colombia.
[3]Ph.D. Titular Professor, Universidad Distrital Francisco José de Caldas, Colombia.

Abstract

Cognitive radio networks through dynamic spectrum access have become an excellent solution to improve the spectral inefficiency in the radioelectric spectrum. The present work proposes a spectral mobility model for cognitive radio networks based on a hybrid model combining AHP and COPRAS with the purpose of determining the best backup channel available for the secondary user. In order to build to this hybrid model, four decision criteria were considered: availability, estimated availability time, signal-to-interference-plus-noise ratio and bandwidth, for each spectral opportunity. The analysis and assessment were established through experimental spectral occupation in real time settings. The assessment metrics included the number of handoffs, the bandwidth and the delay, in the communication with the secondary user. The results were compared with the VIKOR algorithm and a random algorithm. The results obtained show a favorable performance of the proposed AHP-COPRAS algorithm in the selection of spectral opportunities.

Keywords: Dynamic Spectrum Access, Cognitive Radio, Handoff, AHP, COPRAS, VIKOR, Random.

I. INTRODUCTION

Over the past decades, the study of wireless communications has gained relevance given that wireless networks connect almost every person on the planet, making them attractive for users due to their mobility (mobile phones). Currently, there is an increasing demand of the radioelectric spectrum for wireless applications causing some frequency bands to become saturated while others show high availability levels. This reveals an underlying problem of spectral inefficiency. Cognitive radio (CR) presents itself as a promising solution that can mitigate this issue [1] [2].

In cognitive radio networks (CRN), the spectrum mobility is defined as the opportunity-based access of a secondary user (SU) in a licensed frequency band that does not interfere with the activity of the primary user (PU) [3]. Spectral mobility and users play a very important role in the performance of cognitive radio communications where dynamic spectrum access (DSA) and channel selection are crucial [2]. Cognitive radio along with DSA are intended to solve spectral inefficiency and other challenges such as spectral opportunity detection, spectral decision-making, spectral mobility and spectrum distribution [4].

The selection of channels relies on various factors such as availability, capacity, quality and bandwidth of the target channel. A poor selection result may cause multiple spectral handoffs which can hinder the performance of the entire network. The most common approach for channel selection is to use a list of backup [5], [6].

In order to achieve a proper selection of the target channel, this work proposes a hybrid model for the dynamic selection of channels in cognitive radio networks, through the Analytical Hierarchy Process (AHP) and Complex Proportional Assessment (COPRAS) methods. It considers direct and proportional dependencies according to the meaning and utility rate of the available alternatives under the presence of mutually contradictory criteria. This dynamic selection of spectral opportunity involves the following criteria: channel availability (PD), estimated availability time (TED), signal-to-interference-plus-noise ratio (SINR) and bandwidth (BW). AHP is used to determine the weights of each criterion, while the COPRAS method ranks each spectral opportunity. In fact, this algorithm optimizes the decision-making process and factors the influence of maximization and minimization criteria delivering highly accurate results and choosing the best backup channel.

The assessment of the obtained results consists on comparing them two additional models: AHP-VIKOR (Multi-criteria Optimization and Compromise Solution) and random spectrum allocation with the same decision criteria. The analysis and assessment required experimental spectral occupation data in real time settings. The assessment metrics were the number of handoffs, the bandwidth and the delay in secondary user communication.

The AHP algorithm has been widely used to solve decision-making problems in different energy planning scenarios [7], quality service strategies [8], and thermal plants generators [9].

The remainder of the manuscript is structured as follows. Section II discusses related articles. Section III describes all three studied handoff models. Section IV presents the results of the model performance assessment and Section V exhibits a set of conclusions.

II. RELATED WORK

The authors in [10] analyzed two different DSA policies in order to tackle spectral allocation and handoff for SU traffic with two priority classes. The assessment required to derive the blocking possibility, the forced termination possibility and the performance of both priority classes of SU traffic. Furthermore, they researched the backup scenario of the sub-channel for high-priority SU and determined the optimal sub-channel backup through simulations.

The authors in [11] present a hybrid algorithm for the allocation of cognitive radio networks based on AHP and VIKOR algorithms in order to improve the performance in terms of secondary user mobility within cognitive radio networks. The authors [11] compare the results obtained with the proposed algorithm with the GRA and random methods, through simulations with a record of real occupation values captured in the GSM frequency band that represents the real behavior of licensed users. The results show that it is possible to improve the performance of spectral handoff rates in CRN.

In [1], a multivariate algorithm is used for the dynamic selection of channels in cognitive wireless networks. Channel selection is based on the fuzzy analytical hierarchy process (FAHP). Furthermore, the authors showed a new MCDM method where the criteria are determined through a customized Delphi method and FAHP. The weight and sign allocation are computed for two applications classified as better effort (BE) and real time (RT). The results highlight FAHP as a tool that improves spectral efficiency based on smart selection of spectral opportunities.

Multicriteria decision methods have been used recently to make decisions while considering satisfying results. The comparison of this project with the related work shows that the latter did not consider the degree of utility in the selection of spectral opportunity. In this paper, the degree of utility helps determine which priority has the highest value for the chosen channel.

III. METHODOLOGY

The proposed model is described in this section as well as both algorithms included in the comparative assessment.

III.I AHP-COPRAS algorithm

This hybrid algorithm combines the advantages of AHP and COPRAS. At first, the weights for the decision criteria are determined through AHP and then the spectral opportunities are ranked using COPRAS.

The analytical hierarchy process (AHP) was designed to optimize decision-making processes and has been mostly used in decision-making analyses with both quantitative and qualitative components [12]. These tools are based on mathematical programming and seek to reduce the divergence of alternatives conceived by mankind.

AHP has a four-component structure: Problem definition, Hierarchy construction, Judgment matrix construction and Normalized weight calculation [13] y [1]

III.I.I Problem definition

The AHP problem can be deconstructed into four hierarchical levels: objective, criteria, sub-criteria and alternatives. The objective is the decision to be made for the selection of the best available opportunity. In this case, the criteria were the real time applications. The sub-criteria are the variables that affect the preference of one alternative over another: channel availability (PD), estimated channel availability (TED), signal-to-interference-plus-noise (SINR) and bandwidth (BW). The alternatives are all the frequency channel options that change dynamically during spectral handoff, which are assessed by the AHP until one option is chosen.

III.I.II Hierarchy construction

Based on the objective, the criteria, the sub-criteria and the alternatives, a hierarchical structure is built according to the AHP algorithm methodology (Fig.1).

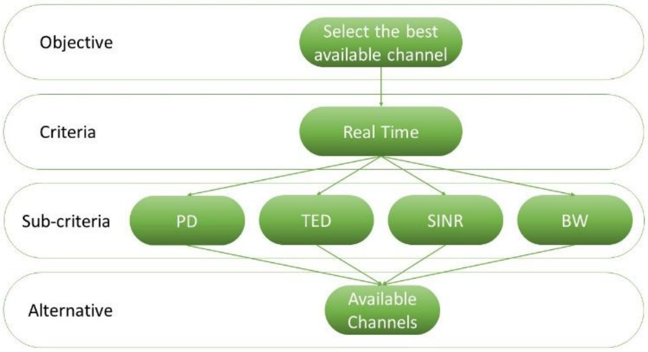

Fig. 1. Proposed FAHP hierarchy.

III.I.III Judgment matrix

The hierarchical structure is used to build the judgment matrix. The assessments determine and compare the highest priority values amongst the possible combinations of criteria and sub-criteria. The importance scale is divided into nine levels. The matrix shows that the most important criteria reduce the delay in the RT scenario and the maximum importance criteria increase speed in the BE scenario. The calculations of the dynamic selection algorithm were performed in MATLAB based on the referenced literature. The creation of the judgment matrix with n criteria (or sub-criteria) is described in Equation 1.

$$A = [a_{ij}]_{nxn} = \begin{bmatrix} a_{11} & a_{12} \cdots & a_{1n} \\ \vdots \ddots \vdots & & \\ a_{n1} & a_{n2} & a_{nn} \end{bmatrix} \quad (1)$$

where $i = j = 1, 2, \dots, n$ and n is the number of attributes.

III.I.IV Weight calculation

The calculation of the normalized weights for each criterion uses the method proposed by [14] due to its simplicity and high quality in the results. The method is based on the geometric mean. For any given criterion, the calculation of the geometric mean Vi for each row of the judgment matrix is defined in Equation 2.

$$Vi = n\sqrt{\pi_{j=1|}^{n}{}^{a_{ij}}} \tag{2}$$

where,

Vi is the geometric mean of row i,

n is the number of sub-criteria,

j represents the columns of the judgment matrix, and

a_{ij} is the matrix value in row i and column j.

The next step consists on calculating the eigenvalue vector r which sets the normalized weights of each criterion as determined by Equation 3.

$$r = [r1, r2, \ldots\ldots, r_n]\ con\ r_i = \frac{v_i}{\sum_{j=1}^{n} v_j} \tag{3}$$

Where,

r is the eigenvalue vector,

$r_1, r_2, \ldots\ldots, r_n$ are the weights for each sub-criterion,

V_i is the geometric mean in row i, and,

V_j is the geometric mean in column j.

III.I.V Consistency index calculation

The objective of this assessment is to validate the results of the AHP algorithm through the consistency index. According to [15], a consistency index below 0.1 means that the algorithm is successful. Equation 4 is used to calculate the index [14].

$$CI = \frac{\sqrt{(\sum_{i=1}^{n}\sum_{j=1}^{n}(\ln a_{ij} \sum \ln \frac{vi}{vj})^2}}{\frac{(n \sum 1)x(n \sum 2)}{2}} \tag{42}$$

Where,

CI is the consistency index,

n is the number of sub-criteria,

i is the value of the judgment matrix row,

j is the value of the judgment matrix column,

a_{ij} is the value of the element in row i and column j,

V_i is the geometric mean in row i, and,

V_j is the geometric mean in column j.

Once the weights of each decision criteria have been established, the COPRAS algorithm is executed. The direct ranking method COPRAS serves as a tool for alternative selection within a set of possible solutions [16]. This method allocates a specific level of uncertainty to a baseline and uses positive and negative values to determine whether the baseline is considered benefit or cost. The priority of the alternative objectives is determined by assessing their relative importance (or quantitative utility) in terms of beneficial and non-directional attributes.

The COPRAS algorithm consists on adding the relative weights w_i to the product between each normalized criterion $r_{ij'}$ and each alternative S_j. After adding all alternatives, they are compared and classified in ascending order. The alternatives with the highest values are superior. The distribution of the relative weight for each criterion was previously computed using AHP. In [17] and [18], the normalization of an alternative criterion $r_{ij'}$ is obtained by dividing the criterion of said alternativer_{ij} by the maximum value of the same criterion for all alternatives $max_j r_{ij}$. At this point, each score r_{ij} is normalized as $r_{ij'}$ (Equation 5):

$$r_{ij'} = \frac{r_{ij}}{max_j r_{ij}} \tag{5}$$

Given that the assessment of criteria that need to be maximized and minimized is carried out separately, the sum of alternative Z_j is the value obtained using Equation 6:

$$Z_j = S_{+j} + \frac{S_{-min} \cdot \sum_{j=1}^{n} S_{-j}}{S_{-j} \cdot \sum_{j=1}^{n} \frac{S_{-min}}{S_{-j}}} \tag{6}$$

In this case, there are no criteria to be minimized, leading to Equations 7 and 8:

$$S_{+j} = \sum_{i=1}^{m} w + i \cdot r_{ij'} \tag{7}$$

$$Z_{+} = S_{+j} = \sum_{i=1}^{m} w + i \cdot rij' \tag{8}$$

Resulting in the final score of each alternative (Z_j). The utility index N_j is used to determine the optimality criterion $Zmax$ as seen in Equation 9:

$$Q_{\max} = max_j\, Q_j\, , i = 1,2 \ldots, m \tag{9}$$

The priority of the alternatives is computed through the satisfaction degree N_i, which indicates that a higher utility rate implies that the priority of an alternative is greater (Equation 10).

$$N_i = \frac{Q_i}{Q\max} 100\%, i = 1,2.\ldots, m \qquad (10)$$

III.II AHP-VIKOR algorithm

This hybrid algorithm combines the best attributes of algorithms AHP and VIKOR. AHP determines the weights of all four decision criteria and then VIKOR ranks the spectral opportunities. The VIKOR algorithm initiates with the assumption that each alternative is assessed according to each criterion functionality. The categorization could be performed by comparing the measurements closer to the ideal alternative [19].

The VIKOR method follows the steps established in [20]. For each parameter j = 1, 2, 3, 0…N, the best and worst values are calculated corresponding to equations (11) and (12).

$$F_j^+ = \{(\max_{i\in M} xij \mid j \in N_b), (\min_{i\in M} xij \mid j \in N_c)\} \qquad (11)$$

$$F_j^- = \{(\min_{i\in M} xij \mid j \in N_b), (\max_{i\in M} xij \mid j \in N_c)\} \qquad (12)$$

Where N_b € N is the set of parameters of benefits and N_c € N is the set of cost parameters. The values of S_i and R_i are computed for $i = 1, 2, 3, \ldots, M$, as seen in Equations 13 and 14.

$$S_i = \sum_{\in N} w_j \frac{(F_j^+ - x_{ij})}{(F_j^+ - F_j^-)} \qquad (13)$$

$$R_i = \max_{i\in M} \left[w_j \frac{(F_j^+ - x_{ij})}{(F_j^+ - F_j^-)} \right] \qquad (143)$$

Where w_j is the importance of the weight parameter j.

The values of Qi are computed for $i = 1, 2, 3, \ldots, M$ as seen in Equation 15.

$$Qi = \gamma(\frac{S_i - S^+}{S^- - S^+}) + (1-\gamma)((\frac{R_i - R^+}{R^- - R^+})) \qquad (15)$$

Where $S^+ \min_{i\in M} S_i$, $S^- = \max_{i\in M} S_i R^+ = \min_{i\in M} R_i$, $R^- \max_{i\in M} R_i$, and $0 \le \gamma \le 1$ belong to the strategy weight.

After obtaining the values of Q for all primary cases of *M,* the candidate spectral opportunities are ordered in a descendent manner. Lastly, the chosen spectral option is given by Equation 16.

$$A^*_{VIK} = \underset{i\in M}{argmin}\, {Q_i}^* \qquad (16)$$

III.III Random algorithm

In the case of the random algorithm, a completely random selection was performed within a set of alternatives comprised of all potential spectral opportunities.

IV. RESULTS

The assessment of the hybrid model FAHP-COPRAS for spectral handoffs is based on the results of three assessment metrics: the average bandwidth, the cumulative number of handoffs and the average cumulative delay. Fig. 2 describes the average bandwidth for the spectral handoff algorithms over a 9-minute transmission using real spectral occupation data. The figure also shows that the behavior is variable in all algorithms. Nonetheless, the behavior of algorithm FAHP-COPRAS has a higher average level compared to the other methods between minutes 1 and 7.

Fig. 3 exhibits the number of cumulative handoffs in each spectral handoff, throughout a 9-minute transmission using simulations based on experimental spectral occupation data.

Fig. 4 describes the average cumulative delay seen in each method, throughout a 9-minute transmission using real spectral occupation data. In order to determine the average cumulative delays in each algorithm, the failed and successful handoffs were considered. Furthermore, the FAHP-COPRAS algorithm outperforms the AHP-VIKOR and Random algorithms.

Table 1 establishes a comparative description of three spectral handoffs for cognitive radio networks in terms of the considered assessment metrics.

In terms of bandwidth, the proposed hybrid algorithm AHP-COPRAS exhibits a superior performance, while seeking to remain close to 350 kHz, while the AHP-VIKOR and Random methods remain below 300 kHz. In terms of handoffs, AHP-COPRAS and AHP-VIKOR behave similarly with a slightly better result from the proposed method. The Random strategy shows a high number of channel swaps, revealing the need for a channel selection mechanism. Since the delay is strongly influenced by the number of handoffs, these two figures show similarly shaped results given that the most significant delay is linked to the time it takes to pause communications, change channels and resume communications. These processes are usually known as successful and failed handoffs.

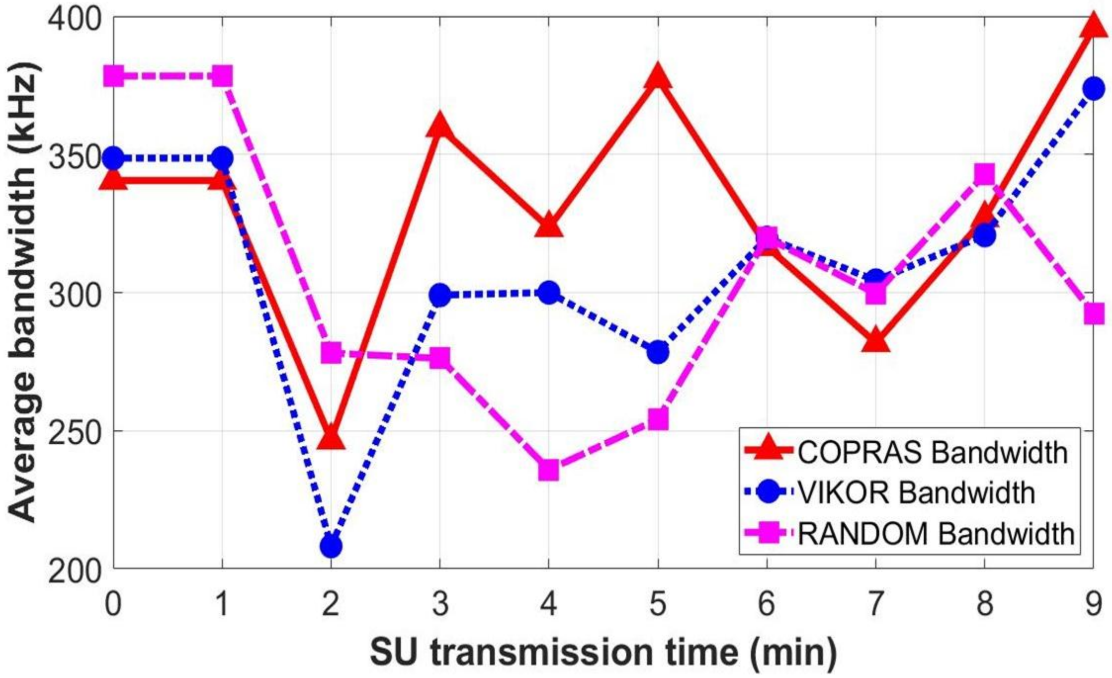

Fig. 2. Average bandwidth
Source: Authors

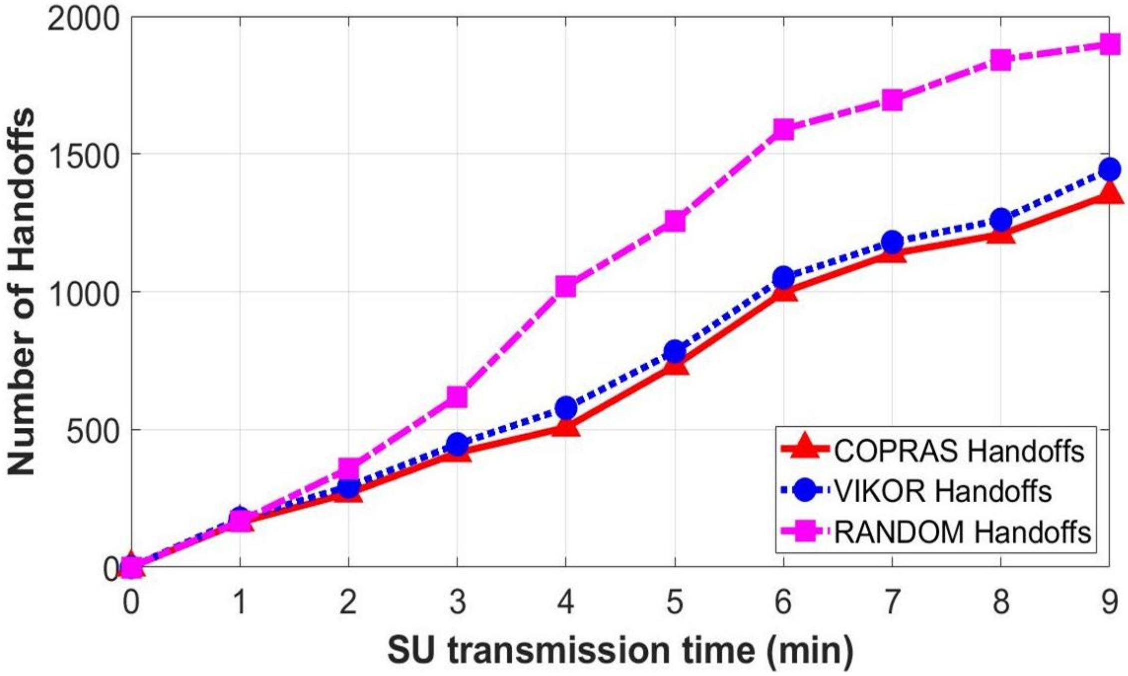

Fig. 3. Total number of cumulative handoffs
Source: Authors.

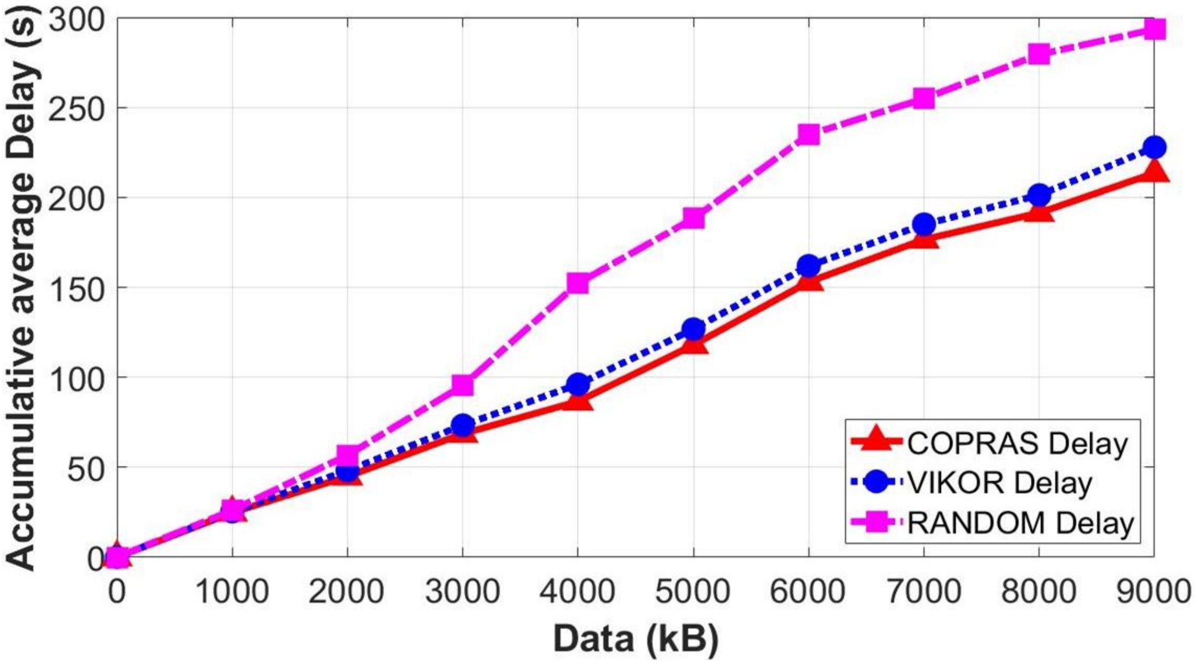

Fig. 4. Average cumulative delay
Source: Authors.

Table 1. Comparative assessment of the spectral handoff models

Algorithm	**Total handoffs**	**Delays**	**Bandwidth**	**Final performance**
VIKOR-AHP	1444	227,830	310,182	Intermediate
Random	1898	293,339	305,562	Very Low
FAHP-COPRAS	1352	213,491	330,917	High

Source: Authors.

V. CONCLUSIONS

The hybrid algorithm AHP-COPRAS was validated through simulations using experimental spectral occupation data. It is an efficient and effective tool of the available frequency channels. The real time application delivered low delays and handoff rates, high accuracy and proper bandwidth compared to other algorithms for the selection of the objective channel. AHP-COPRAS is an interesting solution that marks significant improvements and leads to the optimization of the communication for secondary users without affecting primary users.

ACKNOWLEDGMENT

The authors wish to thank Center for Research and Scientific Development of Universidad Distrital Francisco José de Caldas, for supporting and funding during the course of this research work.

REFERENCIAS

[1] C. Hernandez, C. Salgado, H. López, and E. Rodriguez-Colina, “Multivariable algorithm for dynamic channel selection in cognitive radio networks,” *Springer*, vol. 2015, no. 1, pp. 1--17, Dec. 2015, doi: 10.1186/S13638-015-0445-8.

[2] L. F. Pedraza, F. Forero, and I. P. Páez, “Detección de espectro para radio cognitiva,” *Ingeniare. Rev. Chil. Ing.*, vol. 20, pp. 197--210, 2012, Accessed: Aug. 24, 2021. [Online]. Available: https://scielo.conicyt.cl/scielo.php?pid=S0718-33052012000200007&script=sci_arttext.

[3] C. Hernández, L. F. Pedraza Martínez, and F. H. Martínez Sarmiento, “Algoritmo multivariable para la selección dinámica de canales en redes de radio cognitivas.,” *Tecnura*, vol. 20, pp. 69--88, 2016, doi: 10.14483/udistrital.jour. tecnura.2016.2.a05.

[4] M. T. Rodríguez, “Estudio de mecanismos de acceso dinámico al espectro en radio cognitiva,” 2011, Accessed: Aug. 24, 2021. [Online]. Available: https://repositorio.upct.es/handle/10317/1966.

[5] I. Christian, S. Moh, I. Chung, and J. Lee, “Spectrum mobility in cognitive radio networks,” *IEEE Commun. Mag.*, vol. 50, pp. 114-121, 2012, Accessed: Aug. 24, 2021. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/6211495/.

[6] J. Hernandez Guillen, E. Rodriguez Colina, R. Marcelin Jimenez, and M. P. Chalke, *CRUAM-MAC: A novel cognitive radio MAC protocol for dynamic spectrum access*. 2012.

[7] T. Kaya, C. K.- Energy, and undefined 2010, “Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul,” *Elsevier*, vol. 35, pp. 2517–2527, 2010, doi: 10.1016/j.energy.2010.02.051.

[8] G. Büyüközkan, C. Kahraman, and D. Ruan, “A fuzzy multi-criteria decision approach for software development strategy selection,” *Int. J. Gen. Syst.*, vol. 33, no. 2–3, pp. 259–280, Apr. 2004, doi: 10.1080/03081070310001633581.

[9] D. Choudhary, R. S.- Energy, and undefined 2012, “An STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: A case study from India,” *Elsevier*, 2012, doi: 10.1016/j.energy.2012.03.010.

[10] V. Tumuluru, P. Wang, … D. N.-I. T. on, and undefined 2012, “Performance analysis of cognitive radio spectrum access with prioritized traffic,” *ieeexplore.ieee.org*, 2012, doi: 10.1109/TVT.2012.2186471.

[11] D. Giral and C. H. Páez, “Modelo AHP-VIKOR para handoff espectral en redes de radio cognitiva.,” *Tecnura*, vol. Vol. 19 Nú, 2015, doi: https://doi.org/10.14483/udistrital.jour.tecnura.2015.3.a02.

[12] G. B. Toskano Hurtado, “El Proceso de análisis jerárquico (AHP) como herramienta para la toma de decisiones en la selección de proveedores : aplicación en la selección del proveedor para la Empresa Gráfica Comercial MyE S.R.L.,” *Thesis. Univ. Nac. Mayor San Marcos. Fac. Ciencias Matemáticas. EAP. Investig. Oper. Lima, Perú.*, 2005, doi: https://sisbib.unmsm.edu.pe/bibvirtual/monografias/basic/toskano_hg/toskano_hg.htm.

[13] J. A. Zapata Cortés, M. D. Arango Serna, and W. Adarme Jaimes, “Applying fuzzy extended analytical hierarchy (FEAHP) for selecting logistics software,” *Ing. E Investig.*, vol. 32, pp. 94–99, 2012, Accessed: Aug. 24, 2021. [Online]. Available: http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0120-56092012000100017.

[14] E. Miranda, “Improving subjective estimates using paired comparisons,” *IEEE Softw.*, vol. 18, pp. 87--91, 2001, Accessed: Aug. 24, 2021. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/903173/.

[15] L. K.-E. journal of operational Saaty and U. 1990, “How to make a decision: the analytic hierarchy process,” *Eur. J. ofOperational Res.*, vol. 48, pp. 9--26, 1990, Accessed: Aug. 24, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/037722179090057I.

[16] A. Invidiata, M. Lavagna, and E. Ghisi, “Selecting design strategies using multi-criteria decision making to improve the sustainability of buildings,” *Elsevier*, vol. 139, pp. 58--68, 2018, doi: 10.1016/j.buildenv.2018.04.041.

[17] C.-L. Hwang and K. Yoon, “Methods for Multiple Attribute Decision Making,” pp. 58–191, 1981, doi: 10.1007/978-3-642-48318-9_3.

[18] A. Zavadskas, EK and Kaklauskas, *Determination of an efficient contractor by using the new method of multicriteria assessment*. 1996.

[19] T. Tanino, T. Tanaka, and M. Inuiguchi, *Multi-objective programming and goal programming: theory and applications*, vol. 21. Springer Science \& Business Media, 2013.

[20] E. Stevens-Navarro and V. W. Wong, *Comparison between vertical handoff decision algorithms for heterogeneous wireless networks*, vol. 2. 2006.