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Hybrid Algorithm for Frequency Channel Selection in Wi-Fi Networks

Cesar Hernández, Diego Giral, Ingrid Páez

Abstract**—**This article proposes a hybrid algorithm for spectrum allocation in cognitive radio networks based on the algorithms Analytical Hierarchical Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to improve the performance of the spectrum mobility of secondary users in cognitive radio networks.

To calculate the level of performance of the proposed algorithm a comparative analysis between the proposed AHP-TOPSIS, Grey Relational Analysis (GRA) and Multiplicative Exponent Weighting (MEW) algorithm is performed. Four evaluation metrics are used. These metrics are accumulative average of failed handoffs, accumulative average of handoffs performed, accumulative average of transmission bandwidth, and accumulative average of the transmission delay.

The results of the comparison show that AHP-TOPSIS Algorithm provides 2.4 times better performance compared to a GRA Algorithm and, 1.5 times better than the MEW Algorithm.

Keywords**—**Cognitive radio, decision making, hybrid algorithm, spectrum handoff, wireless networks.

I. Introduction

THE cognitive radio is defined by the Institute of Electrical and Electronics Engineers (IEEE) as “A radio frequency transmitter receiver that is designed to intelligently detect whether a particular segment of the radio spectrum is currently in use, and to jump into (and out of, as necessary) the temporarily-unused spectrum very rapidly, without interfering with the transmissions of other authorized users”. The cognitive radio (CR) is the key technology to use the dynamic spectrum access (DSA), which allows a more efficient use of the radio spectrum [1], [2].

In the CR, unlike the traditional network, there are two types of users, the licensed user or primary user (PU) who pays to use a licensed frequency band, and the unlicensed user or secondary user (SU) who uses opportunistically the PU’s licensed spectrum while it is available and, free up the spectrum resource when the PU requires it and search one new, incrementing significantly the efficient use of the radio spectrum [3], [4]. The described above, where the SU pauses his transmission to change his operating frequency (operating channel), it is known as spectrum handoff. [4].

In the spectrum handoff (SH) is necessary to count with an objective channel which allows performing this process in a quick way, decreasing the interference and the delay, and increasing the average rate of the SU’s data transmission. Accordingly, to find an acceptable objective channel on which the secondary user can continue his data transmission session is the most urgent issue in spectrum mobility. A poor channel selection can cause multiple spectrum jumps (handoff), increase the delay and bit error rate, reduce the data rate and the signal-to-noise ratio, degrading the transmission performance. [1]-[4].

In this paper, a proposal of a hybrid algorithm is presented for the selection of the objective channel. This algorithm is formed by two algorithms, Analytical Hierarchical Process (AHP) which evaluates the decision criteria for the selection of the objective channel, and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) algorithm which evaluates all the spectrum opportunities (available frequencies) and organizes them from the most adequate to the least.

Channel selection depends on the following decision criteria (DC) selected, probability of channel availability (AP), estimated channel time availability (ETA) and the Signal to interference plus noise ratio (SINR) and bandwidth (BW).

This paper presents a comparative analysis of three algorithms: the proposed AHP-TOPSIS, Grey Relational Analysis (GRA) and Multiplicative Exponent Weighting (MEW), for SH in order to contrast their performance.

As a difference with related documents, the performance of the three spectrum handoff algorithms was validated with captured data of spectral occupancy in experiments performed at the Wi-Fi frequency band (2.4 GHz – 2.5 GHz). These data represent the actual behavior of the spectral occupation for this wireless frequency band.

The spectrum handoff algorithms are vital for the SU’s communication performance. In the literature several spectrum handoff models are proposed for cognitive radio networks (CRN), within which the algorithms based on multiple criteria decision making (MCDM) have been the most used, as evidenced in the papers [5]-[16].

The rest of the document is structured as follows. In Section II, a description of related work is presented. Section III describes the three SH Algorithms. In Section IV, the results of the three algorithms are shown. Finally, the conclusions are drawn in Section V.

Cesar Hernandez is an Electronic engineer, Master in Science in Information and Communications, PhD student in Systems Engineering and Computer Science at Universidad Nacional de Colombia. Professor and researcher at the Universidad Distrital Francisco José de Caldas, Faculty of Technology, Bogotá, Colombia. (corresponding author to provide phone: 3112186635; e-mail: cahernandezs@udistrital.edu.co).

Diego Giral is an Electronic engineer, student of Master in Electronic Engineering at Universidad de los Andes. Professor at Universidad Distrital Francisco José de Caldas, Faculty of Technology, Bogotá, Colombia. (e-mail: dagiralr@udistrital.edu.co)

Ingrid Páez is with the Faculty of Engineering of the Universidad Nacional de Colombia, Cra. 45 No. 26–85, Bogota, Colombia (e-mail: ippaezp@unal.edu.co).

II. Design of the Spectrum Handoff Algorithms

SH Algorithms often have multiple variables for channel selection, so the MCDM methods are widely used in such problems, where the relationship between DC are weighted by weights set by the designer, according to his or her requirements.

A. AHP-TOPSIS Algorithm

The AHP-TOPSIS Algorithm is a hybrid algorithm that combines the advantages of AHP and TOPSIS. Firstly, it determines the weights of the four decision criteria through AHP and then performs a ranking of spectrum opportunities through TOPSIS.

AHP Algorithm was developed with four steps: (1) problem definition, (2) construction of the hierarchy, (3) construction of the judgment matrix, and (4) calculation of the normalized weights [17].

The problem **i**s defined, divided and classified as follows: the objective, the criteria and the alternatives. The objective is to select the best target channel available. 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 paper considered only four variables of interest for the proposed multi-criteria decision algorithm due to their 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 channel (BW). The selected criteria were obtained using only experimental data by using the "energy detection" technique, corresponding at frequency channels of the Wi-Fi band (2.4 GHz to 2.5 GHz). Finally, the alternatives are all spectrum opportunities.

Based on the problem definition, the hierarchy structure is constructed. Once the above was carried out, the judgment matrices are constructed in agreement with the AHP Method. The judgment matrices are formed by comparative evaluations of each combination of pair of criteria, to define the level of importance among them. With respect to the alternatives, the AHP-TOPSIS Algorithm evaluates dynamically the alternatives because the frequency channels change constantly their characteristics in time. [17].

With the judgments matrices already defined, the normalized weights were calculated for each criterion, based on the model proposed in [17]-[19].

The development of TOPSIS Algorithm is based on determining two components, the chosen candidate channel is the one which has the shortest distance to the ideal solution and the longest distance to the worst case solution. Having these standards, it is necessary to compare the results to define which solution is closer to the ideal and which is farther [20]. This metric is obtained from Euclidean distance, between criterion and weights, for this the following steps are defined [21]:

1) Normalize matrix decision X using square root normalization method.
2) Build matrix decision with standard weights X,

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1M} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{N1} & \cdots & \tilde{x}_{NM} \end{bmatrix} = \begin{bmatrix} \omega_1\tilde{x}_{11} & \cdots & \omega_M\tilde{x}_{1M} \\ \vdots & \ddots & \vdots \\ \omega_1\tilde{x}_{N1} & \cdots & \omega_M\tilde{x}_{NM} \end{bmatrix} \quad (1)$$

where wi is the weight assigned to criterion (i-th verify sum weights is one).

Ideal and bad solutions are described as:

$$A^{+} = \{(\max \tilde{x}_{ij} \,|j \in X^{+}), (\min \tilde{x}_{ij} \,|j \in X^{-})\} = \{\tilde{x}_1^{+}, \dots, \tilde{x}_M^{+}\}, \quad (2)$$

$$A^{-} = \{(\min \tilde{x}_{ij} \,|j \in X^{+}), (\max \tilde{x}_{ij} \,|j \in X^{-})\} = \{\tilde{x}_1^{-}, \dots, \tilde{x}_M^{-}\}, \quad (3)$$

where I = 1, …N and X+ and X- are benefit and cost sets, respectively. For each alternative, the Euclidean distance D is calculated.

$$D_i^{+} = \sqrt{\sum_{j=1}^{M}\left(\tilde{x}_{ij} - \tilde{x}_j^{+}\right)^2}, \quad i = 1, \dots, N, \quad (4)$$

$$D_i^{-} = \sqrt{\sum_{j=1}^{M}\left(\tilde{x}_{ij} - \tilde{x}_j^{-}\right)^2}, \quad i = 1, \dots, N, \quad (5)$$

Finally, the alternatives are ordered from the highest to the lowest according to the preference index given by:

$$C_i^{+} = \frac{D_i^{-}}{D_i^{+} + D_i^{-}}, \quad i = 1, \dots, N. \quad (6)$$

B. GRA Algorithm

The objective of this algorithm is to establish networks and select candidates that have the highest score according to defined parameters. To achieve the aforesaid, Grey relations between elements of two series are established. The first series contains the best qualities while the other contains comparative entities. Grey coefficient is used to describe relationships between sets calculated from the level of similarity and variability [20], [21]. The GRA method has the following steps [20], [22]:

First reference vector Xo is generated from X matrix, by the choice of minimum values for costs and maximum values for the criteria of benefits. Then the data stream must be normalized to X according to two situations: larger-the-better and smaller-the-better. Then, the relational Grey coefficient is calculated as described by (7):

$$\gamma\left(x_0(i), x_j(i)\right) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0,j}(i) + \zeta\Delta_{max}} \quad (7)$$

where:

$$\Delta_{0,j} = |x_0(i) - x_j(i)| \quad \Delta_{min} = \min_{j \in N}\left\{\min_{i \in M}\{|x_0(i) - x_j(i)|\}\right\}$$

$$\Delta_{max} = \max_{j \in N}\left\{\max_{i \in M}\{|x_0(i) - x_j(i)|\}\right\}$$

where ζ coefficient belonging [0,1], compensates the effect of Δmax, which is generally 0.5.

Finally, the gray relational grade for each of the different data sets is calculated. $\Gamma(x_o, x_i)$ represents the Grey relational grade for the j-th alternative, see (8):

$$\Gamma(x_0, x_j) = \sum_{i=1}^{M} \omega_i \gamma\left(x_0(i), x_j(i)\right) \quad (8)$$

where the weight of the importance for the i-th criteria is w_i.

C. MEW Algorithm

This algorithm has M numbers representing the gain of the criteria, and moreover N numbers are alternatives.

The score of each of these is calculated using (9):

$$S_i = \prod_{j \in N} x_{ij}^{w_j} \quad (9)$$

where X_{ij} is the value of the j-th attribute, and w_j is the weight that is assigned to each attribute. The value of w_j has positive and negative ranges, when it is positive it means is a benefit to the matrix, on the contrary, when the weight is negative it represents a cost factor. According to the results the highest score network is selected, and the lowest will be the last option [21].

III. Experiments and Simulations

With the captured occupancy spectrum data, the behavior of the primary users was modeled and a dichotomous time series was constructed (1 available channel, 0 unavailable channel) for each frequency channel of the Wi-Fi band, between 2.4 GHz and 2.5 GHz. The occupancy spectrum information was determined with the energy detection technique using a spectrum analyzer and the false alarm probability model. [23].

Later, a simulation environment was developed based on the dichotomous time series (time step 1/3s), obtained previously. Where the proposed spectrum handoff algorithm selects the channel objective in accordance with the historic information (HACIA ATRAS) of the decision criteria (AP, ETA, SINR, BW); if the mentioned channel is unavailable a second channel is selected from its classification list, and so on. The aforesaid process is repeated for the GRA and the MEW algorithm. Each time step saves the corresponding information of the used frequency, the bandwidth and throughput, to subsequently calculate and chart the evaluation metrics.

Four evaluation metrics were calculated: (1) Accumulative average number of failed handoffs (Fig. 1), (2) Average of transmission bandwidth (Fig. 2), (3) Accumulative average transmission delay (Fig. 3) and, (4) Accumulative average throughput (Fig. 4).

Finally, Table I summarizes the level of comparative performance for each one of the metrics in respect of each one of the three selected handoff algorithms.

From this table, it can be deduced that in comparison the best SH is AHP-TOPSIS with an average value of 100.

TABLE I
SUMMARY OF THE COMPARATIVE PERFORMANCE OF THE THREE SH

SH Algorithm	Comparative performance				
	Failed Handoff	Bandwidth	Delay	Throughput	Overall
GRA	13.88	76.19	48.07	29.16	**41.83**
MEW	45.45	90.47	80	45.83	**65.44**
AHP-TOPSIS	100	100	100	100	**100**

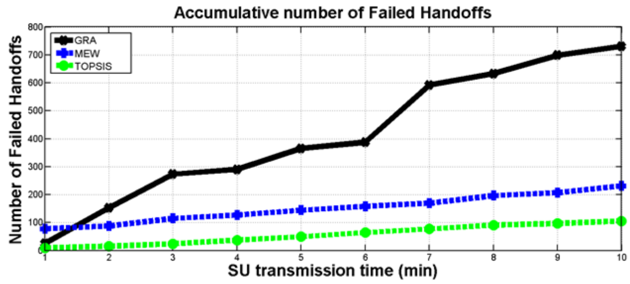

Fig. 1 Accumulative average number of failed handoffs

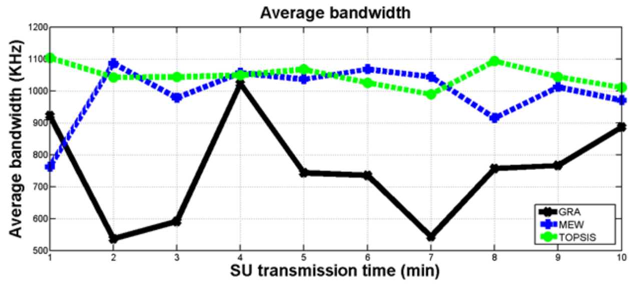

Fig. 2 Average of transmission bandwidth

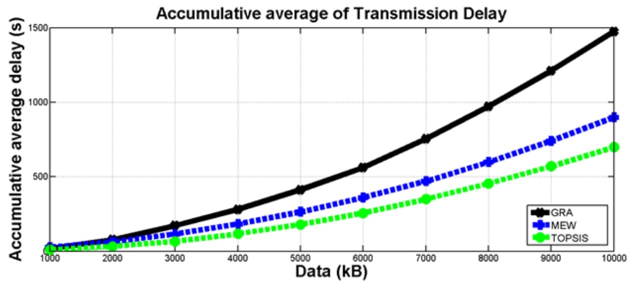

Fig. 3 Accumulative average of transmission delay

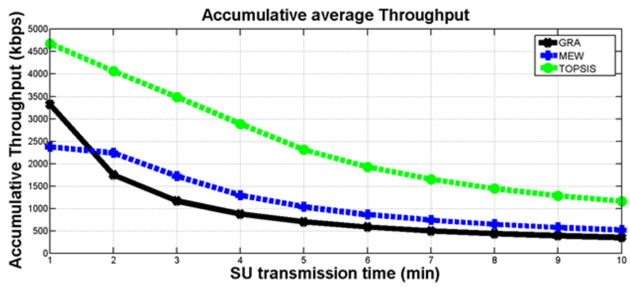

Fig. 4 Accumulative average throughput

IV. Conclusion

This research paper presents a comparative analysis between three algorithms for the selection of the objective channel during the SU's communication, based on the multiple criteria decision making. The comparative evaluation was performed with four evaluation metrics in a simulation environment based on real spectrum occupancy data captured in the Wi-Fi band.

The simulation results show that between the three algorithms, AHP-TOPSIS Algorithm provides an efficient process to select frequency channels in Wi-Fi networks.

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Cesar Hernandez was born in Villavicencio, Colombia. He received the degree in electronics engineering at Universidad Distrital Francisco José de Caldas. He obtained his specialization degree in Interconnection Networks. He received his Master Degree in Information Sciences and Communications at Universidad Distrital Francisco José de Caldas, and currently is a PhD candidate for System Engineering and Computing at Universidad Nacional de Colombia. Associate Professor at Universidad Distrital Francisco José de Caldas. Member of Smart Internet and ARMOS research groups. His research interests include cognitive radio and networking areas.

Diego Giral was born in Bogotá, Colombia. He received the degree in electronics engineering from Universidad Distrital Francisco Jose de Caldas. He was a young researcher in Colciencias (2014). Currently, he is a Master's degree candidate in Electronics Engineering at Universidad de los Andes and he is a professor at Universidad Distrital Francisco José de Caldas. His research interests include Cognitive Radio and Optimization areas.

Ingrid Páez was born in Colombia. She received the degree in electronics engineering at Escuela de ingenieros de Colombia and has a PhD degree in telecommunications engineering at Universidad de Cantabria. Currently, she is a research professor at Universidad Nacional de Colombia. Her research interests include networking areas.