MCDM Spectrum Handover Models for Cognitive Wireless Networks

Cesar Hernández, Diego Giral, Fernando Santa

Abstract**—**Spectrum handover is a significant topic in the cognitive radio networks to assure an efficient data transmission in the cognitive radio user's communications. This paper proposes a comparison between three spectrum handover models: VIKOR, SAW and MEW. Four evaluation metrics are used. These metrics are, accumulative average of failed handover, accumulative average of handover performed, accumulative average of transmission bandwidth and, accumulative average of the transmission delay.

As a difference with related work, the performance of the three spectrum handover models was validated with captured data of spectrum occupancy in experiments performed at the GSM frequency band (824 MHz - 849 MHz). These data represent the actual behavior of the licensed users for this wireless frequency band.

The results of the comparison show that VIKOR Algorithm provides a 15.8% performance improvement compared to SAW Algorithm and, it is 12.1% better than the MEW Algorithm.

Keywords**—**Cognitive radio, decision making, MEW, SAW, spectrum handover, VIKOR.

I. INTRODUCTION

THE radio spectrum is a good that each country regulates because it is a limited resource, this spectrum is distributed to different users according to its use and it can be divided into two groups, licensed frequency bands and unlicensed frequency bands. When a frequency range is administrated by an entity, it states that is licensed and therefore, the users who access to it are licensed too. For instance, the companies that provide wireless communication services, the licensed users are all the ones who connect to this network, also called primary users (PU). Furthermore, in the unlicensed frequency bands, there is not an entity that administrates the network access. When an unlicensed user accesses to a licensed frequency band is called a secondary user (SU). Currently, these access policies (licensed band and unlicensed band) to the radio spectrum are fixed. Several studies have revealed that the licensed frequencies use is between 15% and an 85%, showing the underutilization of this important resource. In the case of cellular networks, the assigned frequency bands are currently saturated, while assigned frequency bands to other applications have little demand as the assigned frequencies to digital television. The aforementioned shows a low level in the efficient spectrum use, hence, it is necessary to change the spectrum access.

The next generation networks proposed a dynamic spectrum access (DSA) [1], [2], which represents a novel way to take advantage efficiently of the spectrum. The aforesaid is based on the opportunistic transmission and reception of the SU on the licensed bands without affecting in any way the PU.

The technology that allows performing the DSA is the Cognitive Radio (CR), and within the CR, the spectrum mobility and specifically the spectrum Handover models, take a relevant role in the performance and quality of service of the wireless communications.

The spectrum handover (SH) can be defined as the process whereby a SU changes its operating frequency due to the arrival of a PU to a channel occupied by the SU [3], [4].

This paper states a comparative analysis of three algorithms for SH in order to contrast their performance. The decision criteria selected to choose the best target channel are: probability of channel availability (AP), estimated channel time availability (ETA) and the Signal to interference plus noise ratio (SINR) and bandwidth (BW). Contrary to other related papers, the handover model evaluation was done with real spectrum occupancy data. Another difference is that the variables and weights to be evaluated were carefully selected and classified by significance.

The rest of the paper 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.

II. RELATED WORK

In the cognitive radio, the models based on multi criteria decision making (MCDM) have been used in research works [5]-[10] to select the frequency channel target during the spectrum handover. The characteristics of the MCDM models make them a good alternative to shape the spectrum handover process. Some of the spectrum handover models proposed on the literature are: Simple Additive Weighting (SAW) [11], Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [11], Multiplicative Exponent Weighting (MEW) [12], Grey Relational Analysis (GRA) [13], Elimination and Choice Translating Priority (ELECTRE) [14], Weighted Markov Chain (WMC) [15], Multicriteria Optimization and

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Compromise Solution (VIKOR) [16] y Analytical Hierarchical Process (AHP) [17]. The AHP algorithm has proved to be an efficient alternative to evaluate and select the best spectrum opportunities [6], [7], [18].

III. DESIGN OF THE SPECTRUM HANDOVER MODELS

SH Models often have multiple variables for channel selection, consequently the MCDM methods are widely used in such problems, where the relationship between decision criteria are weighted by weights set by the designer, according to his requirements.

A. SAW (Simple Additive Weighting)

It is developed through a decision matrix where each intersection of the parameters, criteria and alternatives are assigned a weight, at the discretion of the designer. This gives a weighted for each of the networks which are being evaluated, known as Ranking, the alternative with the highest score will be the solution to be applied [19].

The calculation of alternative Ai is given by (1) [19]:

$$u_i = \sum_{j=1}^{M} \omega_j r_{i,j} \quad \forall i \in 1,\ldots, \tag{1}$$

where $r_{i,j}$ belong to X, and the sum weights equals to one is satisfied.

B. MEW (Multiplicative Exponent Weighting)

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

The score of each of these is calculated using (2):

$$S_i = \prod_{j \in N} x_{ij}^{w_j} \tag{2}$$

where Xij is the value of the j-th attribute, and wj is the weight that is assigned to each attribute. The value of wj 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 [20].

C. VIKOR (Multi-criteria Optimization and Compromise Solution)

The classification method of commitment (VIKOR) assumes that each alternative is evaluated according to each criterion function; the classification of commitment can be developed through the comparison of the measures that are closer to the ideal alternative [18].

The VIKOR Method follows these steps [18], [21].

1. For each parameter j = 1,2,3, ..., N, to determine the best and worst value given by (3) and (4).

$$F_j^+ = \{(\max_{i \in M} x_{ij} \,|j \in N_b), (\min_{i \in M} x_{ij} \,|j \in N_c)\} \tag{3}$$

$$F_j^- = \{(\min_{i \in M} x_{ij} \,|j \in N_b), (\max_{i \in M} x_{ij} \,|j \in N_c)\} \tag{4}$$

where N_b belonging to N, is the set of benefit parameters, and N_c belonging to N, is the set of cost parameters.

2. Values of S_i and R_i for i = 1,2,3…,M are estimated by (5) and (6):

$$S_i = \sum_{j \in N} w_j \frac{(F_j^+ - x_{ij})}{(F_j^+ - F_j^-)} \tag{5}$$

$$R_i = \max_{i \in N} \left[w_j \frac{(F_j^+ - x_{ij})}{(F_j^+ - F_j^-)} \right] \tag{6}$$

where wj is the importance of weight parameter j.

3. Qi values for i = 1, 2, 3, ..., M are calculated by (7).

$$Q_i = \gamma \left(\frac{S_i - S^+}{S^- - S^+} \right) + (1 - \gamma) \left(\frac{R_i - R^+}{R^- - R^+} \right) \tag{7}$$

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 the parameter γ with $0 \leq \gamma \leq 1$, it belongs to the weight of the strategy.

4. Given the values for Q, for all i belonging to M, are ranked highest to lowest, candidate networks. The selected network is given by (8):

$$A_{VIK}^* = \arg\min_{i \in M} Q_i^* \tag{8}$$

IV. EXPERIMENTS AND SIMULATIONS

In order to evaluate the performance level of each handover model a novel simulation environment was developed through a trace of real spectrum occupancy data taken from the GSM frequency band (824 MHz - 849 MHz). This allows shaping the real PU behavior and performing a more accurate evaluation and validation of the performance of each handover model.

The spectrum occupancy data trace corresponds to a one-week observation, taken inside a measuring campaign for Bogotá city in Colombia. To determine the occupancy or availability of each channel of the GSM band, the energy detection technique was used.

During the execution of the simulation, the information is stored by four evaluation metrics. (1) Accumulative average number of failed handover (Fig. 1), (2) Accumulative average number of handover (Fig. 2), (3) Accumulative average of transmission bandwidth (Fig. 3) and, (4) Accumulative average transmission delay (Fig. 4). The represented values in Figs. 1-4, correspond to the average value of the gathered results after performing several simulations.

Table I describes a comparison between the three selected spectrum handover models. The results of this table show that the VIKOR model has the best performance in all the evaluation metrics.

TABLE I
SUMMARY OF THE COMPARATIVE PERFORMANCE OF THE THREE SH

SH Algorithm	Comparative performance				
	Failed Handover	*Handover*	*Bandwidth*	*Delay*	*Overall*
MEW	72	87.5	95.7	96.5	87.9
SAW	58	90	98.5	90.3	84.2
VIKOR	100	100	100	100	100

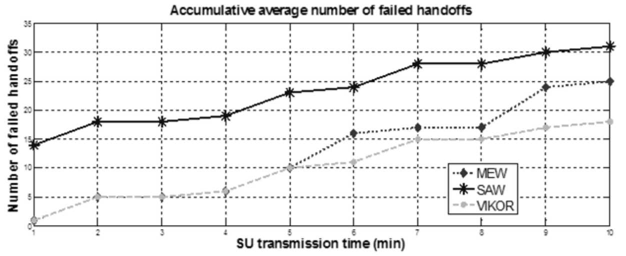

Fig. 1 Accumulative average number of failed handover

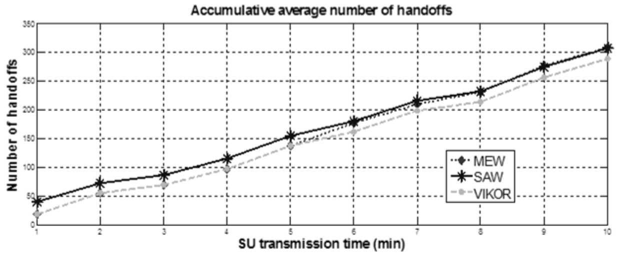

Fig. 2 Accumulative average number of handover

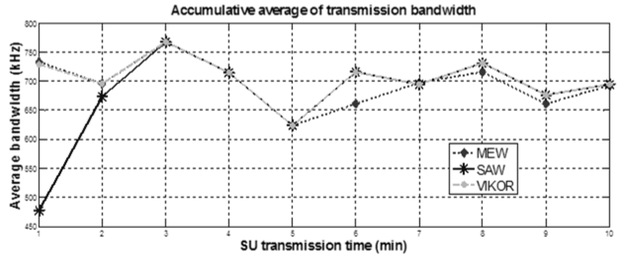

Fig. 3 Accumulative average of transmission bandwidth

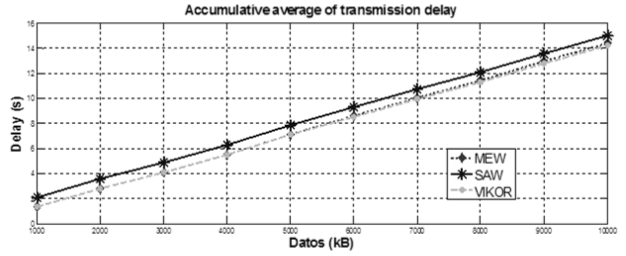

Fig. 4 Accumulative average of transmission delay

V. CONCLUSION

This paper states a comparison between three spectrum handover models. The models are based on multi criteria decision making algorithms and the comparison is based on four evaluation metrics focused on handover, failed handover, bandwidth and delay.

The evaluation and validation of the three algorithms are made through extensive simulations, using real spectrum occupancy data, the aforementioned was taken from the GSM mobile band.

The simulation results show that VIKOR Algorithm has low average number of handover, high rate of bandwidth utilization, and low average transmission delay. The VIKOR Algorithm provides efficient and effective process to select frequency channels.

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.

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