Performance evaluation of a proposal for spectrum assignment based on combinative distance-based assessment multicriteria strategy

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Article Info

Article history:

Received Apr 12, 2024
Revised Jul 11, 2024
Accepted Jul 17, 2024

Keywords:

Cognitive radio networks
Combinative distance-based assessment
Decision-making models
Multicriteria strategies
Spectral mobility

ABSTRACT

Cognitive radio networks offer an alternative to low spectral availability in some frequency bands due to their high demand for frequency channels. This article proposes to improve the spectral assignment based on the combinative distance-based assessment multicriteria algorithm. The metrics obtained are compared with a simple additive weighting algorithm and a RANDOM selection. To establish the algorithm 's performance, five quality-of-service metrics are used: number of handoffs, number of failed handoffs, average bandwidth, average throughput, and cumulative average delay. From the analysis of the results obtained, combinative distance-based assessment (CODAS) presented the best result for the cost metrics with the lowest levels, and for the benefit metrics, the highest levels were obtained.

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1. INTRODUCTION

Over the last decade, the number of devices connected to the Internet has grown exponentially. The use of free spectrum for various applications has also increased [1]. Studies of the use of the spectrum show the inefficiency with which the majority of the radio spectrum is used [1]. The investigations have shown that government allocation policies have failed, and the assigned bands are overused or underused, a characteristic that prevents the electromagnetic spectrum from operating efficiently [2]. Due to this, different Communications Commissions have generated proposals to improve the allocation models. Communications the inefficient distribution of expectations [2]. A solution to improve the inefficient use of the spectrum is cognitive radio (CR) [3]–[5] the operation of a network through the CR requires using a cognitive cycle, which is presented in Figure 1, this cycle allows for intelligent adaptations, through learning and the exchange of information [6].

Unlike traditional networks, in the cognitive radio networks (CRN), there are two types of users: the primary user (PU) and the secondary user (SU). The SU is the user who accesses the spectrum opportunistically; the PU is the user who accesses the spectrum in a licensed manner [7]. The objective of a CRN is to provide access to an SU to an available frequency channel in the licensed band without affecting the performance or communication of the PU [7]. This process where the SU changes frequency is called spectral mobility [3].

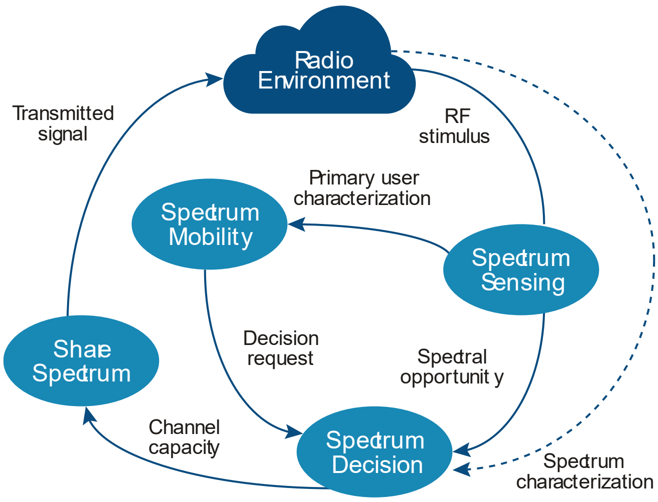

Figure 1. Cognitive cycle structure (Martinez *et al.* [8])

Decision-making is relevant in CRNs; a good methodology allows for improving quality-of-service (QoS) indicators. In CRNs, it is essential that the SUs can access the spectrum according to the required QoS characteristics [8]. An incorrect channel selection generates different problems associated with spectral mobility [9]. To select spectral opportunities, decision-making techniques must analyze various variables. Multi-criteria decision making (MCDM)-based algorithms are widely used in this type of problem due to their efficient results and low computational load. With the MCDM it is possible to establish which channels have the greatest number of spectral opportunities. For the MCDM, the relationship between the decision criteria is measured through weights, which are adjusted according to the designer's requirements [10]. The names and respective acronyms of some multicriteria techniques are described: i) TOPSIS: technique for order preference by similarity to ideal solution [10], ii) VIKOR: multi-criteria optimization and compromise solution [10], iii) PROMETHE: preference ranking organization methods for enrichment evaluations [11], iv) WASPAS: method utilizes the concept of ranking accuracy [12], v) DEMATEL: decision-making trial and evaluation laboratory [13], [14], vi) MOORA: Multi-objective optimization based on radius analysis [15], [16], vii) BWM: Best–worst method [17], and viii) FUCOM: full consistency method [15].

According to the review of the literature, different applications of the algorithms were found; for example, DEMATEL is used in the investigation to analyze the factors that influence the decision to adopt virtual reality technology by the real estate companies. The results showed that several aspects influenced the intention of the real estate companies; however, the most important one [14] was the price ratio, especially as a contribution to the management of COVID-19 [14]. MOORA is the multiple objectives optimization method by ratio analysis. Among the criteria used for decision-making, we have average scores, psychological evaluations, mathematical evaluations, and interviews. The exposed matrix is applied because each criterion has an evaluation value. MOORA is a simple strategy to implement, but it is characterized by the robustness of the decisions [16]. combinative distance-based assessment (CODAS) is an MCDM algorithm that uses the combined evaluation based on distance, where the Euclidean distance and the Taxicab are calculated; it has been used by companies dedicated to the steel industry to help evaluate and select the best supplier among six possible alternatives [18], [19].

This work aims to implement the CODAS algorithm [7], [20] in a decision-making process in CRNs. CODAS has shown good results in applications associated with decision-making, making the process more equitable, clear, and efficient [19]. To establish the good performance of the algorithm, five metrics are used: number of handoffs, number of failed handoffs, average bandwidth, average throughput, and cumulative average delay. For the evaluation to be fair, the metrics obtained in CODAS are compared with simple additive weighting (SAW), an MCDM technique that has shown efficient results in spectral assignment. Additionally, a second comparison is made; in this scenario, a RANDOM selection of the channels is made, and the metrics obtained in CODAS are compared, as input information spectral occupancy data is used, which can be randomly generated or obtained through measurements, for this work, and in order to evaluate CODAS in realistic scenarios, spectral power measurements are used.

This article is structured in four sections with the Introduction. In section 2, the methodology is presented. In section 3, the results are presented. Finally, in section 5, the conclusions are presented.

2. CODAS MULTICRITERIA STRATEGY

This work implements the MCDM CODAS for spectrum selection in cognitive wireless networks. For the comparative analysis, SAW and a RANDOM channel selection methodology are used; spectral mobility metrics are used for the performance analysis. Figure 2 presents the proposed methodology for the spectrum selection using CODAS through blocks.

The model initially starts from the spectral information data provided by the behavior of the users, especially the PU, since this is the information from which the proposed algorithm makes decisions. These spectral information data were obtained through a previously carried out spectral measurement campaign, whose information was processed and organized in a spectral availability matrix made up of ones (availability) and zeros (occupancy). Subsequently, the information from the availability matrix is delivered to the proposed Feedback CODAS algorithm, whose behavior is described later. The proposed algorithm delivers as a result a ranking of spectral opportunities through which the communication of the SU is carried out.

During the SU communication, it is possible that the selected spectral opportunity is required by a PU, in which case it is necessary to release it and select a new spectral opportunity, according to the ranking provided by the proposed algorithm. The previous process is called spectral mobility. Finally, from the data obtained during the spectral mobility process, five evaluation metrics are constructed: Number of handoffs, number of failed handoffs, average bandwidth, average throughput, and cumulative average delay.

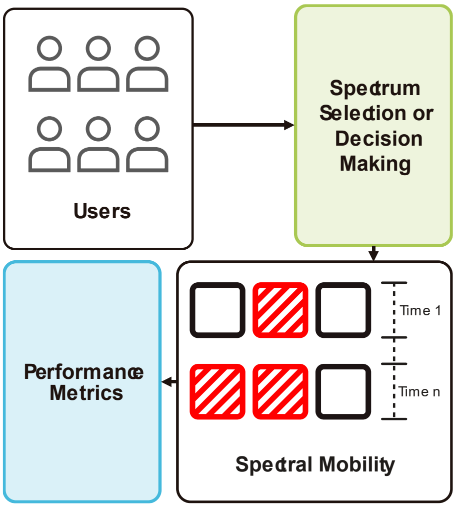

Figure 2. Proposed methodologies for the spectrum selection using CODAS

2.1. Users

The evaluation of the strategy is carried out by implementing a radio environment with real information on the behavior of the PUs. This information corresponds to a spectral power matrix in the Wi-Fi frequency band, obtained through a measurement process using the energy detection technique. Table 1 describes the size of the measured power spectral matrix. The channels are characterized by the columns and the time by the rows.

Table 1. Measured spectral power matrix

Frequency Band	Rows (time)	Columns (channels)	Total data
Wi-Fi	2.490.000	550	1.369.500.000

2.2. Proposed model based on CODAS

The decision matrix must be generated x. The (1) presents this matrix. $x_{i,j}$ is the selection (decision) criterion j for channel i and w_j represent the weight (w) to the selection criterion j.

$$\bar{x} = \begin{pmatrix} \omega_1 x_{1,1} & \cdots & \omega_j x_{1,j} \\ \vdots & \ddots & \vdots \\ \omega_1 x_{i,1} & \cdots & \omega_j x_{i,j} \end{pmatrix} \quad (1)$$

Subsequently, the selection criteria are established, which must be obtained for each m; the meaning, description, and its respective acronym are presented in Figure 3.

In order to carry out a comparative analysis, SAW and RANDOM are implemented in addition to CODAS. The selection was made from the previous revision [21]. Combinative distance-based assessment (CODAS): establish the alternatives from the Euclidean distances and the disturbance of Taxicab. Where the Euclidian distance is the main measure and the distance of Taxicab, the most desirable ideal negative solution is when the value of the distance is the largest [18], [20]. The methodology to implement CODAS is described below. Figure 4 presents the flowchart.

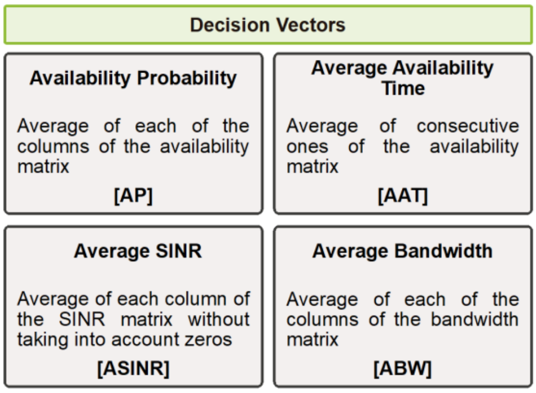

Figure 3. Description of decision criteria

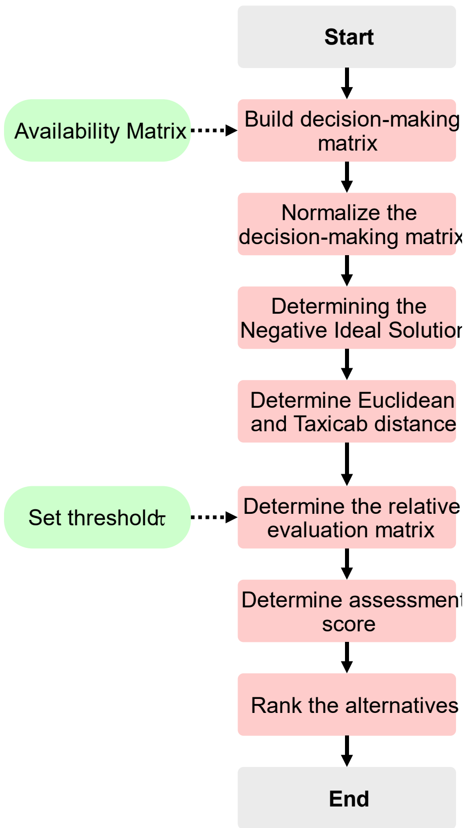

Figure 4. CODAS flow chart

– Establish the selection matrix or decision-making matrix through (1), where $x_{ij}(x_{ij} \geq 0)$ defines the efficiency value of the i^{th} alternative in the j^{th} criterion $i \in \{1,2,\ldots,n\}$ y $j \in \{1,2,\ldots,n\}$.

– Determine the normalized selection (decision) matrix through (2). Where N_b and N_c represent the benefit $a < nd$ cost criteria set.

$$n_{ij} = \begin{cases} \frac{x_{ij}}{\max_i x_{ij}} & if \;\; j \in N_b \\ \frac{\min_i x_{ij}}{x_{ij}} & if \;\; j \in N_c \end{cases} \tag{2}$$

– Determine the normalized weight through (3).

$$r_{ij} = w_j n_{ij}$$
$$\sum_{j=1}^{m} \omega_j = 1 \tag{3}$$

– Set the negative ideal solution according to (4).

$$ns = \left[ns_j\right]_{1xm} \text{ where } ns_j = \min_i r_{ij} \tag{4}$$

– Determine the Euclidean and taxi distance for each negative ideal solution according to (5) and (6).

$$E_i = \sqrt{\sum_{j=1}^{m}\left(r_{ij} - ns_j\right)} \tag{5}$$

$$T_i = \sum_{j=1}^{m}\left|r_{ij} - ns_j\right| \tag{6}$$

– Build the relative evaluation matrix according to (7), (8), and (9). $k \in \{1, 2, \dots, n\}$, establishes the threshold for the Euclidean equality. τ in is the threshold parameter responsible for establishing the decision. As a recommendation, this value is adjusted in the interval [0.01 - 0.05]. In this work, it is assumed that $\tau = 0.05$ with the variable u for the calculations.

$$R_a = [h_{ik}]_{n \times n} \tag{7}$$

$$h_{ik} = (E_i - E_k) + \left(\psi(E_i - E_k)x(T_i - T_k)\right) \tag{8}$$

$$\psi(x) = \begin{cases} 1 \; if \;\; |x| \geq \tau \\ 0 \; if \;\; |x| < \tau \end{cases} \tag{9}$$

– Determine the respective evaluation score for each of the alternatives. This score is obtained through (10).

$$H_j = \sum_{k=1}^{m} H_{ik} \tag{10}$$

– Finally, the evaluation score (***H***) is ordered in descending order. The highest ***H*** gives the best options; the worst options are given by the lowest ***H***.

Simple additive weighting (SAW) establishes a ranking for each alternative according to the decision criteria. The spectral opportunity with the highest score will be selected. In (11), the mathematical model for SAW is presented. The SAW index is determined from w_j and $x_{i,j}$, ($Index_{saw}$).

$$Index_{SAW} = \sum_{j=1}^{M} \omega_j x_{i,j}$$
$$\sum_{j=1}^{N} \omega_j = 1 \tag{11}$$

2.3. Spectral mobility assessment strategy

The spectral mobility is quantified through the changes established by the decision vector. One or several SUs must change column (channel) when busy and change row when the information is transmitted [22], [23]. Considering that the rows represent the instants of time, the spectral mobility process is carried out until the time of interest and/or simulation is completed [24], [25]. The availability, the changes of channels, and the characteristics are stored to quantify the indicators of QoS [26].

2.4. Validation of the proposed model

For the evaluation to be fair, the metrics obtained in CODAS are compared with SAW, an MCDM technique that has shown efficient results in spectral assignment. Additionally, a second comparison is made; in this scenario, a RANDOM selection of the channels is made, and the metrics obtained in CODAS are compared, as input information spectral occupancy data is used, which can be randomly generated or obtained through measurements, for this work, and to evaluate CODAS in realistic scenarios, spectral power measurements are used. Validation is carried out according to five evaluation metrics: bandwidth, delay, throughput, failed handoffs, and total handoffs.

3. RESULTS

A set of figures obtained by performing the validation of the performance of the implemented CODAS methodology is presented. Figure 5 presents the performance metrics: bandwidth, delay, throughput, failed handoffs, and total handoffs compared to RANDOM and SAW. The criteria used are matrix average availability (PD), mean time to availability (TED), matrix average SINR (PSINR) and bandwidth matrix average (PWA).

3.1. CODAS vs RANDOM

Figure 5 presents the number of handoffs. Figure 6 presents the number of failed handoffs. Figure 7 presents the cumulative average delay (s). Figure 8 presents the average bandwidth (kHz). Finally, Figure 9 presents the average throughput (kbps).

3.2. CODAS vs. SAW

Figure 10 presents the number of handoffs. Figure 11 presents the number of failed handoffs. Figure 12 presents the cumulative average delay (s). Figure 13 presents the average bandwidth (kHz). Finally, Figure 14 presents the average throughput (kbps).

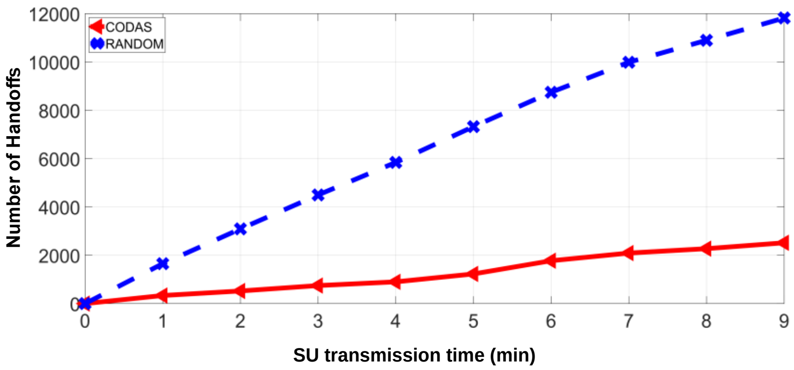

Figure 5. Number of handoffs

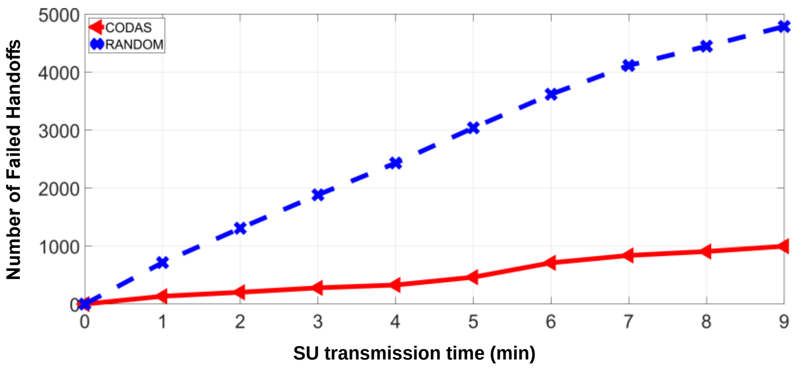

Figure 6. Number of failed handoffs

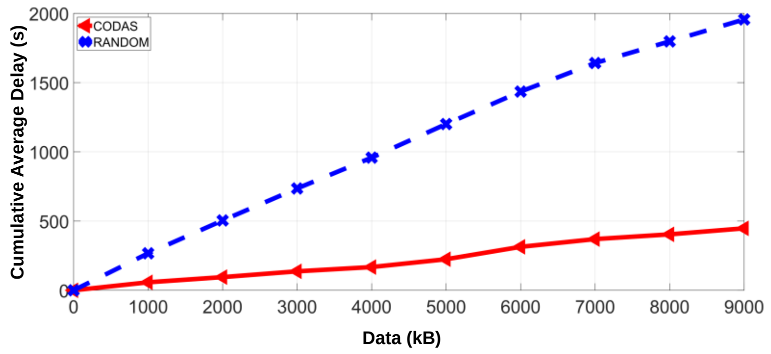

Figure 7. Cumulative average delay (s)

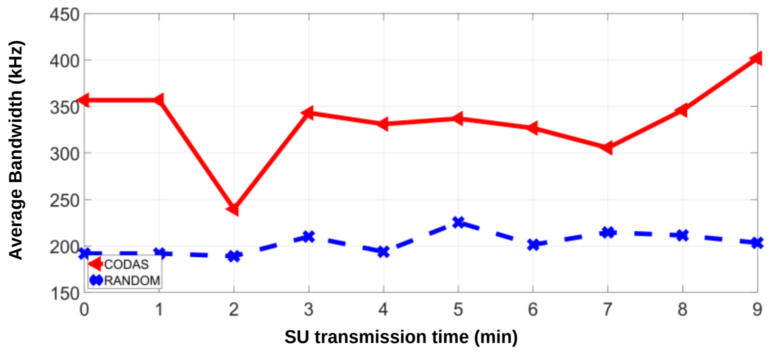

Figure 8. Average bandwidth (kHz)

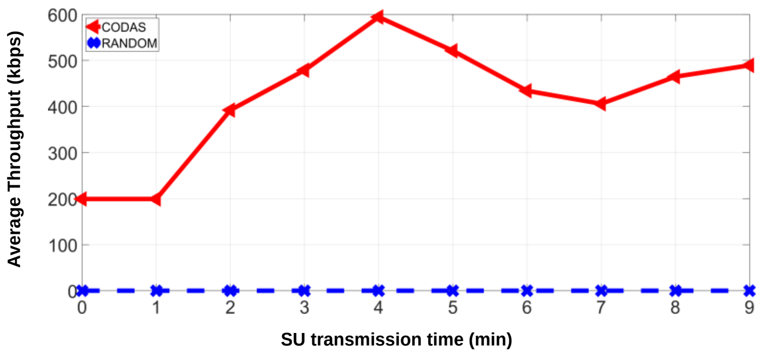

Figure 9. Average throughput (kbps)

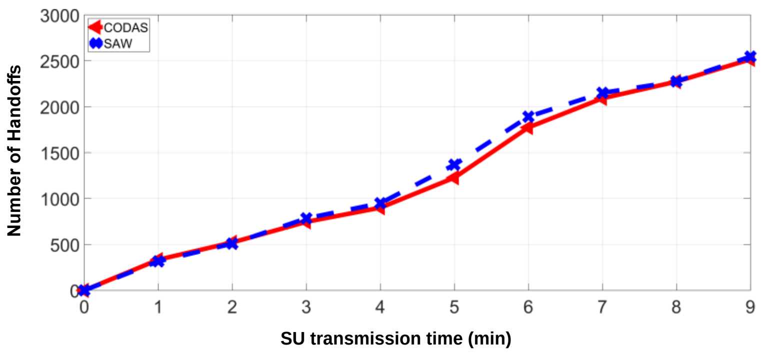

Figure 10. Number of handoffs

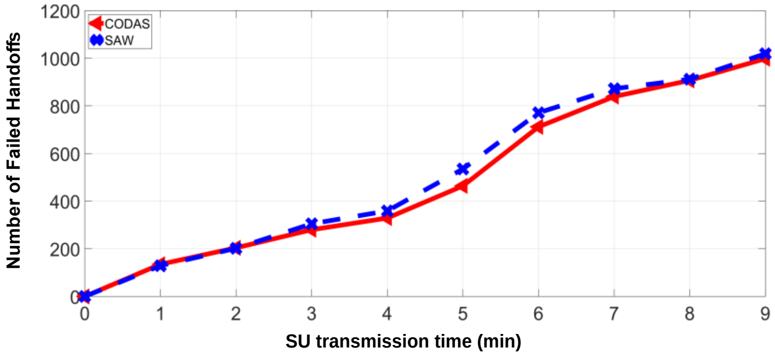

Figure 11. Number of failed handoffs

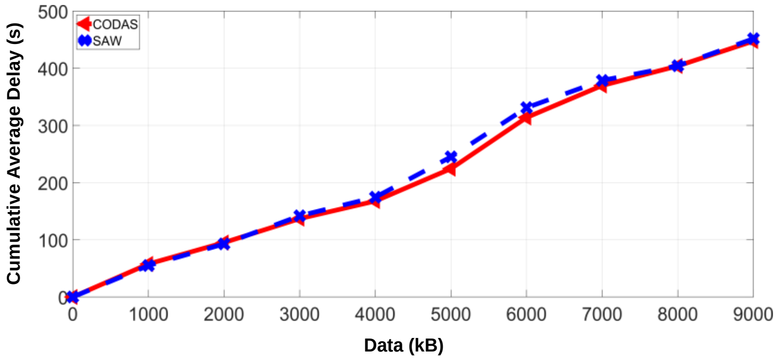

Figure 12. Cumulative average delay (s)

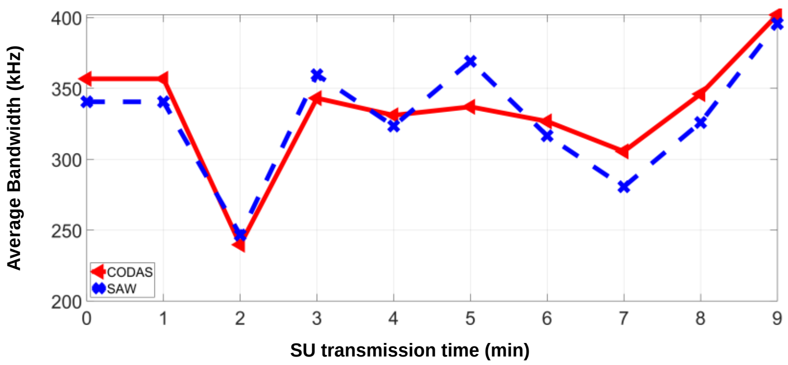

Figure 13. Average bandwidth (kHz)

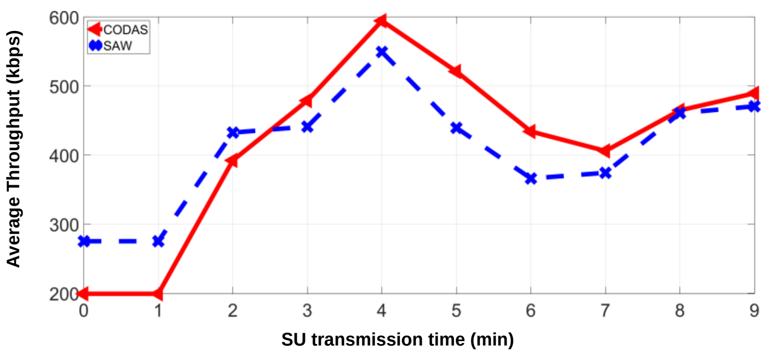

Figure 14. Average throughput (kbps)

3.3. Discussion

Table 2 and Table 3 describe the comparative evaluation of the three spectral handoff models for CRN regarding the five-evaluation metrics run. According to the cost metrics: number of handoffs, number of failed handoffs, and cumulative average delay, CODAS obtains the best performance with the least value. CODAS obtains the best results according to the benefit metrics, bank width, and throughput.

The selection of SAW to comparatively evaluate the performance of the feedback CODAS algorithm was made based on the results that SAW has obtained in previous research where most of the time it takes first place for having not only the best results but also a low computational cost. In this case Feedback CODAS manages to improve the performance of SAW; however, it only achieves this by approximately 3%. On the other hand, the RANDOM selection is carried out to be able to measure by what percentage the performance of the CRN improves when it has a strategy for the selection of spectral opportunities compared to not having one. In this case the difference is 370%, that is, almost 4 times better. The previous results achieved by Feedback CODAS are obtained thanks to the fact that its algorithm is much more robust than SAW, however, it would be interesting to analyze how much computing processing feedback CODAS requires compared to SAW.

Although the proposed algorithm has a good comparative performance in general terms, it is important to highlight the limitations that it may have in the real world on a larger scale. The main limitation lies in the availability matrix since a greater amount of information requires, on the one hand, a greater amount of memory and, on the other, a greater amount of information processing, which translates into greater delays and greater energy expenditure. The above is possible to solve through a collaborative strategy in which various SUs have diverse information that can be shared based on more relevant information vectors such as rankings of spectral opportunities.

Table 2. Cost metrics

Algorithms	Maximum values		
	Number handoffs	Number failed handoffs	Cumulative average delay
CODAS	2516	998	447.54
SAW	2545	1019	451.72
RANDOM	11822	4788	1956.20

Table 3. Benefit metrics

Algorithms	Average values	
	Average bandwidth	Average throughput
CODAS	334.45	417.88
SAW	329.86	408.44
RANDOM	203.29	0

4. CONCLUSION

One solution to improve the inefficient use of spectrum is CR. The objective of the CR is to provide access to an available channel without affecting performance. Spectral decision is a key aspect in CRNs to improve QoS indicators. MCDM-based algorithms are widely used in this type of problem due to their efficient results and low computational load. With the MCDM, it is possible to establish the channels according to the analysis of spectral opportunities. This work uses real spectral occupancy data to implement the CODAS algorithm for the spectrum selection process in a CRN. The following metrics were used: number of handoffs, number of failed handoffs, cumulative average delay, average bandwidth, and average throughput (kbps). The results were compared with the metrics obtained for the SAW technique and for a RANDOM selection of the channels. According to the results obtained, CODAS presents the best result; for the cost metric, the lowest levels were obtained, and for the benefit metric, the highest levels were obtained. The number of failed handoffs is approximately 40% of the total handoffs, so the number of total handoffs is of greater importance when comparatively analyzing the performance of two-channel selection algorithms since the number of increased handoff delays during SU communication is greater. However, the number of failed handoffs also provides a measure of accuracy in the algorithm since they are channels that the algorithm determines as available but are busy when the change is made. An important analysis is the impact that implementing spectral decision techniques such as the proposed Feedback CODAS algorithm can have on the quality of service of mobile communications, where frequency bands are generally saturated. Relevant future work would be implementing a collaborative strategy that increases the proposed algorithm's effectiveness and efficiency.

ACKNOWLEDGEMENTS
This work was supported by Oficina de Investigaciones of the Universidad Distrital Francisco Jose de Caldas.

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