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Spectral opportunity selection based on the hybrid algorithm AHP-ELECTRE

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ABSTRACT

Due to an ever-growing demand for spectrum and the fast-paced development of wireless applications, technologies such as cognitive radio enable the efficient use of the spectrum. The objective of the present article is to design an algorithm capable of choosing the best channel for data transmission. It uses quantitative methods that can modify behavior by changing quality parameters in the channel. To achieve this task, a hybrid decision-making algorithm is designed that combines AHP algorithms and adjusts the weights of each channel parameter, using a priority table. The ELECTRE algorithm processes the information from each channel through a weight matrix and then delivers the most favorable result for the transmitted data. The results reveal that the hybrid AHP-ELECTRE algorithm has a suitable performance, which improves the throughput rate by 14% compared to similar alternatives.

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1. INTRODUCTION

The electromagnetic spectrum is a highly valuable public resource which is limited and operators often do not manage to cover all places in which information transmission is authorized, which could take place in large acres of woods or underground structures such as tunnels or bridges [1]; Cognitive radio is a response to this problem seeking to sense the spectrum and identify the availability of channels so these can be reused in another type of communication such as low-coverage internet or telephone services, without affecting main user activity [2–3]. In order to make this possible, the spectrum must be permanently sensed and jumps between channels must be carried out while avoiding the interruption of primary user communications [4]. These jumps are achieved through a series of decision-making algorithms that measure different quality parameters of the channel such as bandwidth and power to subsequently choose the best path [5–6]. These systems can make decisions based on programs that optimize operation parameters, with the goal of harnessing the available spectrum [7–8].

The programs loaded onto cognitive radio devices are decision-making algorithms that analyze and extract data that can generate predictions, detect exceptions, isolate patterns and improve the results obtained as more data is given to the algorithms [9].

When a proper selection of channels is not in motion, communications suffer from high handoff rates which can significantly affect the quality of the service, leading to an increase in failure probability and signal delays. Furthermore, channel selection tends to be time-consuming given that a single spectrum sampling task can detect more than 400 channels [10]. Each measurement will determine its power, bandwidth, signal-to-noise ratio, among other variables to be processed. This tedious process does not guarantee that the best decision is actually made [11–13].

Therefore, decision-making algorithms are being used to deliver a response based on quantitative analysis [14]. A hybrid algorithm is proposed to make the best decision using quality of service parameters, where the weight matrix is created by an AHP algorithm. The latter offers subjective assessments for each criterion that varies according to the priority matrix and the type of data. The channel matrix is created by the ELECTRE algorithm in tandem with the weight matrix, which delivers convenient results on a short-term basis. The main contribution of this work consists in the development of a hybrid algorithm between AHP and ELECTRE algorithms, which enables a 14% improvement in the throughput rate compared to other algorithms such as AHP, MOORE or SAW.

The development detailed in this document involves three parts. Section 2 sets out the context and explains the methodology of decision-making algorithms. Section 3 discusses the development of the proposed algorithm, through an example based on previously gathered spectral occupancy data. Lastly, the results of the proposed algorithm are assessed and compared with other decision-making alternatives in Section 4.

2. RESEARCH METHOD

2.1 Decision-making algorithms

The Hierarchical Analysis Process is a tool used to model non-structured problems in different areas, such as politics, economic sciences, social sciences and management, to make decisions on multiple criteria [15]. This methodology is used to solve problems where there is a need to prioritize different options and subsequently make a most convenient choice. In this technique, the decisions may vary from simple personal or qualitative decisions to highly complex and quantitative decision-making scenarios [16] .

The AHP technique helps analysts to organize the critical aspects of a problem in a tree-like hierarchical structure, thus reducing complex decisions to a series of comparisons that allow the hierarchization of the assessed criteria.

Fuzzy set theory is similar to human reasoning regarding the use of approximate information and uncertainty to make decisions. It was designed specifically to mathematically represent uncertainty and vagueness and offer formal tools to tackle intrinsic inaccuracy problems [17].

In order to classify a set of decision-making alternatives based on different criteria, AHP comprises the following steps [18]:

- Define the assessment criteria for the decision objective and establish a hierarchical framework.
- Compare decision-making elements in pairs.
- Estimate the relative weights of decision-making elements.
- Rate the decision-making alternatives in terms of the aggregated weights of the decision-making elements.

2.2 ELECTRE

The ELECTRE (Elimination et Choice Translating Reality) method is an eliminatory and selective algorithm of multiple criteria [19]. This method facilitates the comparisons between alternative schemes through the use of a pondered sum technique. It also uses several mathematical functions to indicate the dominant degree of an alternative over the remaining options [20]. The procedure is based on a decision matrix and an overclassification relation is used in order to deliver an improvement matrix. An alternative overclassifies another alternative and makes it a part of the set of the most favorable alternatives when it is considered to be at least as good as the other ones, given the set of attributes. This requires that the concordance between both surpasses a certain index and the discordance does not exceed another index. Both indexes are established beforehand [21–22].

For the implementation of the ELECTRE algorithm, the following steps were carried out [23].

Construction of the condordance matrix: Each index $c\ (i,\ k)$ of this matrix of the alternatives Ai and Ak is obtained by adding the weights related to each criterion in which alternative i is better than alternative k as shown in Equation (1) [23].

$$\mathrm{C(a,b)} = \sum_{\mathrm{j|rj\ (a)>rj\ (b)}}^{\infty} \mathrm{wj} + 0.5 \sum_{\mathrm{j|rj\ (a)=rj\ (b)}}^{\infty} \mathrm{wj} \quad (1)$$

Normalization of the decison matrix: The decision-making matrix is normalized through

Equation (2) [23].

$$\mathrm{vij} = \frac{\mathrm{rij}}{\sqrt{\sum_{\mathrm{i=1}}^{m} (\mathrm{rij})^2 \mathrm{j}}} \ , \forall \mathrm{j} = 1,2, \dots , \mathrm{n} \tag{2}$$

Building the discordance matrix: the discordance index matrix is computed. Each index $d(i,\ k)$ within this matrix is obtained among the alternatives Ai and Ak as a result of the highest difference between the criteria for which the alternative *i* is determined by the alternative *k*, and then that amount is divided by the difference in absolute value between the normalized and pondered indexes of the decision matrix from *i* and *k* [23], see Equation (3).

$$\mathrm{D(i,k)} = \frac{\max(\mathrm{i,k})\ \overline{\mathrm{v}}\mathrm{j}\ (\mathrm{k}) - \overline{\mathrm{v}}\mathrm{j(i)}}{\max \forall (\mathrm{i,k})\ |\overline{\mathrm{v}}\mathrm{j}\ (\mathrm{k}) - \overline{\mathrm{v}}\mathrm{j(i)}|} \tag{3}$$

2.3 Adequation of samples

To obtain the most subjective information, a sample of 400 channels was chosen in different time instants where the status of the channel is measured. If a channel showed power values over -95 dBm then it is occupied and a 0 is entered in its corresponding position. Otherwise, the channel is available and a 1 is inputted. For instance, Table 1 shows 7 channels with several power sampling processes.

Table 1. Sensed channels in dBm.

Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7
-99,260002	-99,260002	-99,711998	-98,660004	-97,183998	-99,363998	-98,956001
-99,288002	-99,288002	-95,435997	-94,064003	-97,400002	-93,431999	-95
-100,440002	-100,440002	-97,643997	-97,916	-96,484001	-95,307999	-96,388
-99,356003	-99,356003	-96,304001	-97,452003	-96,823997	-95,480003	-94,575996
-94,384003	-94,384003	-100,720001	-97,912003	-83,195999	-78,972	-93,783997
-98,260002	-98,260002	-97,075996	-96,823997	-97,199997	-99,143997	-94,171997
-97,975998	-97,975998	-97,267998	-94,484001	-98,428001	-96,856003	-97,891998

The output of the previously described procedure corresponds to Table 2.

Table 2. Analyzed channels in binary form.

Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7
1	1	1	1	1	1	1
1	1	1	0	1	0	1
1	1	1	1	1	1	1
1	1	1	1	1	1	0
0	0	1	1	0	0	0
1	1	1	1	1	1	0
1	1	1	0	1	1	1

After this process is carried out for all 400 channels, a matrix of the same size as the original one is built, with binary values where rows represent time and columns represent channels. This stage rerpresents the first channel fitlering task.

2.4 Parameters for comparison

For the development of this work, the following quality of channel parameters were chosen:

Bandwidth (BW)

Bandwidth refers to the interval of frequencies that a channel is able to support or process. To determine this parameter, an average value in which channels are available is computed and, since each channel has a bandwidth of 100 kHz, these can be added leading to a channel with higher capacity. Furthermore, it is possible to adjust the máximum size of the channel by altering the algorithm. However, it would mean that less channels would be derived and bandwidth would be wasted in text-based data that does not require significant bandwidth.

Estimated time of availability (TED)

This parameter is obtained by adding consecutive records available over time and then averaging them.

Availability percentage (%Dis)

It is the average rate in which a channel is available over a certain period of time. To compute this parameter, a sample adequation is carried out that is represented by the following equation:

Signal-to-noise ratio (SNR):

It is defined as the margin between the power of the transmitted signal and the power of the noise that corrupts it. Its formula is represented by Equation (4).

$$SNR = 10log_{10}\frac{Potencia\ Señal}{Potencia\ Ruido} \quad (4)$$

3. PROPOSED HYBRID ALGORITHM

The proposed hybrid algorithm is designed to choose the channel that best suits the type of data that is transmitted. The decision-making process consists on three parts as shown in Figure 1.

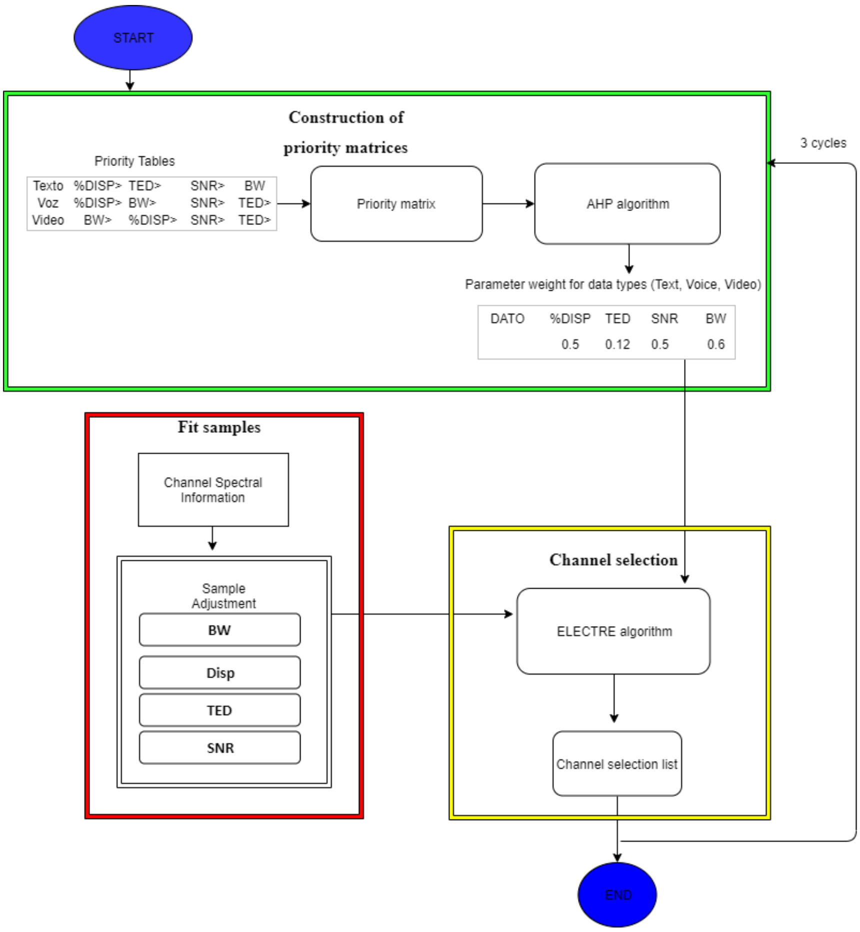

Figure 1. Proposed hybrid model.

The first stage involves building the priority matrices: The priority table serves as a reference where the order of each criterion is determined. Afterwards, three matrices are built: starting from the vertical axis, the first criterion is compared with the others and the most appropriate value is assigned according to the table of existing values. After setting the priority matrices, the AHP algorithm processes the information and consistency is validated. The process output is a weight vector. The second stage consists on adjusting samples: the records previously obtained from channels are loaded and processed to determine the criteria to be analyzed. The first criterion is bandwidth (BW) which reduces the number of channels to be used since a large bandwidth represents the union of various channels. The result of this process is a smaller matrix and the other criteria are obtained to build the matrix. Finally, the channel selection process requires to enter the channel matrix and weight vector as inputs in the algorithm so it can process them and deliver a list of the top-ranked channels. The process is repeated three times by changing the type of data.

The importance of all elements should be compared under the same factor so that the relation between upper and lower levels can be established [24]. In the implementation of the proposed algorithm, the AHP algorithm is used in the weight calculation procedure. These values will affect the final decision of the channel depending on their importance as shown in Table 3, while still validating that the matrix is balanced enough to achieve better results [25].

Table 3. Classification values

Numeric scale	Verbal scale
1	Equally important
3	Moderately important
5	Significantly important
7	Evident or strong importance
9	Extremely important
2,4,6,8	Intermediate levels

In Table 4, the weight matrix is selected for the text data type.

Table 4. Weight matrix

Texto	BW	TED	%Disp	SNR
BW	1	9/1	7/3	5/3
TED	1/9	1	1/3	1/7
%Disp	3/7	3/1	1	3/7
SNR	3/5	7/1	7/3	1

3.1 Normalization

The purpose of normalization is to adjust the matrix values in a scale from 0 to 1 as seen in Equation (5).

$$ValNor(i,j) = \frac{A(i,j)}{\sum_{j=1}^{j} A(i,j)} \quad (5)$$

The result of the normalization process is shown in Table 5.

Table 5. Normalized weight matrix.

Texto	BW	TED	%Disp	SNR
BW	0.4674	0.4500	0.3889	0.5147
TED	0.0519	0.0500	0.0556	0.0441
%Disp	0.2003	0.1500	0.1667	0.1324
SNR	0.2804	0.3500	0.3889	0.3088

3.2 Consistency validation

The first step in the consistency validation is to compute the consistency index shown in Equation (6).

$$CI = \frac{\sum_{i=1}^{i} ValNor(i) - T}{T-1} \quad (6)$$

Where T is the matrix size.

Equation (7) is used to calculate the random index.

$$RI = \frac{1.98-(T-2)}{T} \quad (7)$$

Equation (8) is used to calculate the eigenvalue.

$$Vp = CI/RI \quad (8)$$

An eigenvalue below 0.1 means that there is considerable consistency. Otherwise, signifcant consistencies are shown [11], [25]. It is recommended to reconsider and modify the original values of the comparison matrix. The values obtained in the previous matrix can be found in Table 6.

Table 6. Weights for text data.

BW	TED	%Disp	SNR
0.4552	0.0504	0.1623	0.3320

Repeating the same procedure with voice, video and text-type data leads to the results in Table 7.

Table 7. Priority table obtained for AHP.

	BW	TED	%Disp	SNR
Text	0.4552	0.0504	0.1623	0.3320
Voice	0.6805	0.1032	0.1248	0.0915
Video	0.5207	0.0876	0.1330	0.2587

Afterwards, each parameter is passed on one by one to the ELECTRE algorithm. This algortihm takes the information from channels and weigths in order to select the best channel that meets the predefined conditions. This algorithm seeks to maximize the parameters BW, TED, %Disp and reduce the SNR parameter with Equations (9) and (10).

$$Vmin(i,j) = \frac{\max(ri)-ri}{\max(ri)-\min(ri)} \quad (9)$$

$$Vmax(i,j) = \frac{ri-\min(ri)}{\max(ri)-\min(ri)} \quad (10)$$

4. RESULTS AND ANALYSIS

4.1 Comparative results of the algorithms

Table 8 shows the results obtained by processing the channel matrix with the algorithms ELECTRE, MOORE and SAW for the text type data. Each value represents the channel chosen in each algorithm.

Table 8. Channels selection

Channels	ELECTRE	MOORE	SAW
1	23	258	1
2	73	220	143
3	121	40	176
4	40	23	154
5	220	209	187
6	12	121	209
7	154	12	198
8	198	198	132
9	165	73	165
10	258	165	220

Figure 2 presents the results of the ELECTRE, MOORE and SAW algorithms in the form of a chart where the values given to each signal can be detailed.

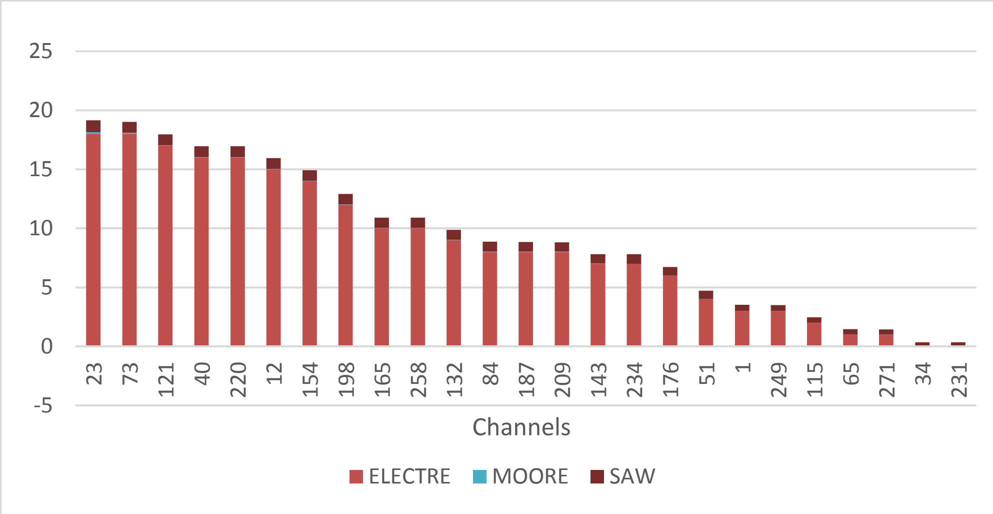

Figure 2. Unified results for the number of channels.

In order to analyze the performance of the proposed hybrid algorithm, failed handoff (Figure 3), bandwidth (Figure 4) and throughput (Figure 5) metrics are analyzed and compared with the AHP and Random algorithms.

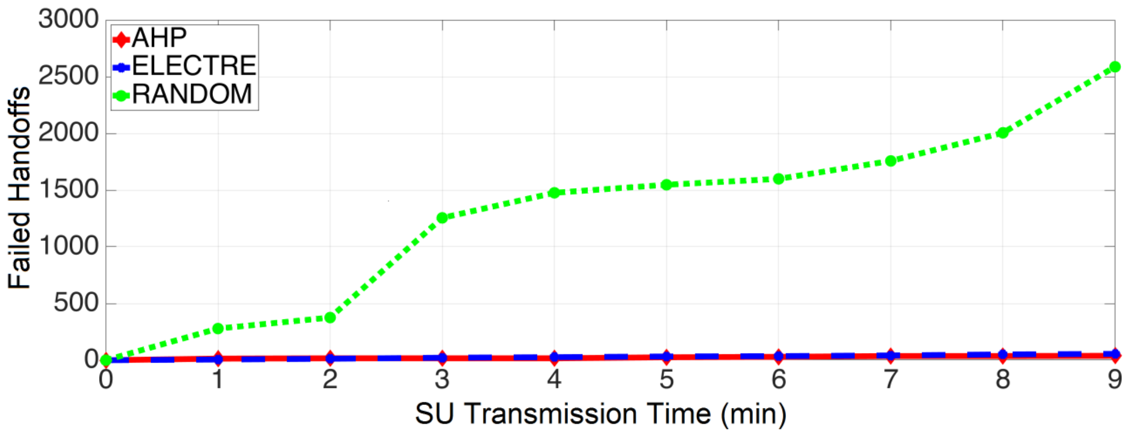

Figure 3. Failed handoffs

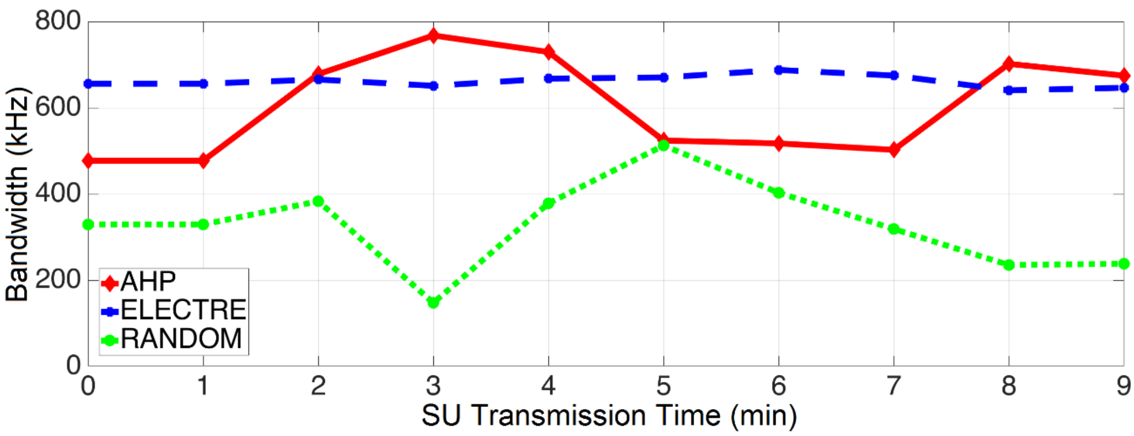

Figure 4. Bandwidth.

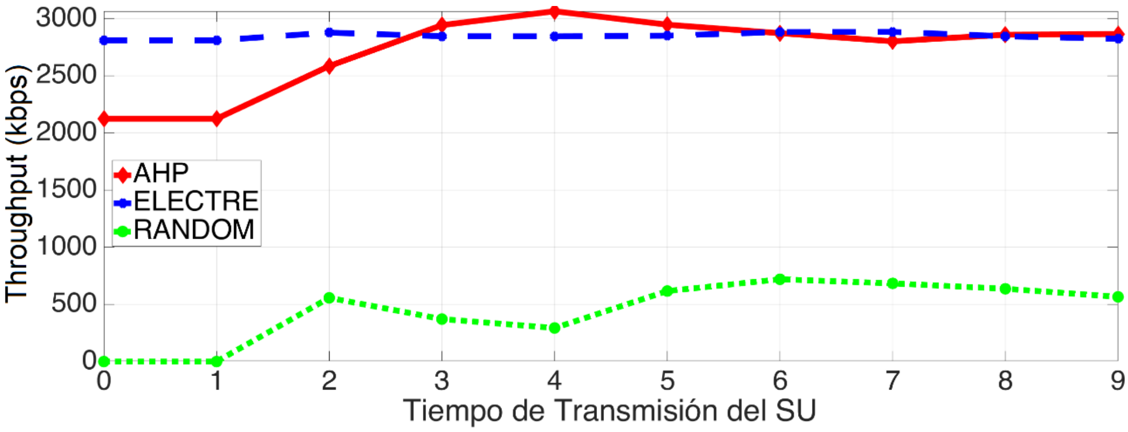

Figure 5. Throughput results for the analyzed algorithms.

The charts for failed handoffs, bandwidth and throughput show that the behavior of the proposed algorithm is stable over time. The detected alterations are significantly low in comparison to the alternatives. The throughput chart reveals that the average success rate is higher in each message in addition to a significantly low level of variation for this criterion.

One of the most troubling issues in spectrum opportunity analysis is the handoff metric which pertains to intermittencies in communications. The proposed solution strongly reduces this variable as seen in the previous figures.

Table 9 shows the results obtained in terms of the evaluation metrics for ELECTRE, AHP and RANDOM. The best averaged score of the metrics is shown by ELECTRE.

Table 9. Evaluation metrics for the analyzed algorithms.

Metric	ELECTRE	AHP	RANDOM
Handoffs	94.6%	100%	2%
Bandwidth (kHz)	100%	92.1%	50%
Throughput (kbps)	99.7%	100%	19.2%
Score	**98.1**	97.3	23.7

After analyzing the variations evidenced in previous charts, the following results are obtained:

- ✓ In the handoff chart, the Random algorithm has a variation of 3800 ms while AHP has a variation of 200 ms and the proposed algorithm has a variation of 100 ms.
- ✓ The throughput chart shows that the Random algorithm has a variation of 600 kbps while AHP has a variation of 27900 kbps and the proposed algorithm has a variation of 100 kbps.
- ✓ The bandwidth chart shows that the Random has a variation of 300 kHz while AHP has a variation of 340 kHz and the proposed algorithm has a variation of 30 kHz.

5. CONCLUSION

The proposed algorithm is proven to be a valid and effective method for channel selection. The results obtained for each data type (text, voice and video) are completely objective and based on the analysis of each quality parameter.

The technique is also compared to commonly used options, revealing that the former delivers more significant results in terms of throuhgput, handoff and bandwidth, and thus increassing the reliability of the decisions made by the algorithm.

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