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MOORA approach for Channel Decision in Cognitive Radio Network

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Abstract:

In the cognitive radio network, channel decision is a critical assignment to utilize the unused spectrum band as a secondary user without interfering with the primary user. Thus different criteria of the available spectrum are exploited as per the requirement of the secondary user to establish connectivity with the network for data transmission. Here Multi-objective Optimization based on Ratio Analysis i.e., the MOORA algorithm is anticipated as multiple criteria decision-making method i.e., MCDM technique for channel selection in the cognitive radio environment. MOORA method acquires contradictory appearances such as criteria and alternatives available. A matrix of the response of alternatives to the criteria is considered and ratio analysis is performed to find the ranking of the available channel. Finally, a decision-making problem with different weighted matrix based on the user application and criteria is illustrated and results show that the proposed MOORA algorithm outperforms similar other algorithms in terms of diverse criteria features, complexity, and practicality.

Keywords: *Channel Decision, Cognitive Radio, Spectrum Band, Multiple Criteria Decision Making, Dynamic Spectrum Allocation (DSA), Data Transmission, Multi-Objective Optimization Based On Ratio Analysis.*

1. INTRODUCTION

The invention of the cognitive radio network was put forward by J. Mitola in 1998 and later published by Gerald Maguire and Joseph Mitola in the year 1999[1]. The dynamic CRN system consists of spectrum sensing and spectrum decision. Spectrum sensing composed of finding the unutilized spectrum holes and also responsible for searching and analyzing the attributes of the available spectrum [2]. In cognitive radio, the distributed spectrum sensing algorithm chooses the spectrum that allows extreme information rate for the cognitive user while the cooperative algorithm chooses the spectrum which will be advantageous for the overall system throughput [3]-[5]. In spectrum decision, spectrum access judgment and spectrum handoff takes place.

At the beginning of 21st-century advances in wireless technologies like Wi-Fi, Bluetooth and mobile telephony achieved an extraordinary focus around the world. Cognitive radio innovation can extensively participate with its essential role in the field of wireless communication and also in internet-based applications [6]. To maintain a good quality of services these technologies need an efficient transmission spectrum band. With the over increasing demand of spectrum by current and upcoming technologies fixed spectrum allocation (FSA) may face a problem of frequency scarcity [7]. According to the recent study of the Federal Communication Commission, only 15% to 85% of frequency spectrum space is utilized by FSA [8].

To address the issues with spectrum inadequacy, the dynamic spectrum allocation (DSA) technique is introduced. DSA technique works in a real-time environment. With DSA, the secondary user may use licensed spectrum bands according to the requirement of secondary users with no intervention to the principal user. Cognitive radio technology can play a role model in dynamic spectrum allocation in the future.

Spectrum sensing is the very initial process in cognitive radio communication and can be defined as the process of determining the spectrum hole by continuous observation over the status of primary user activity over the available frequency spectrum.

May – June 2020
ISSN: 0193-4120 Page No. 1750 - 1760

Spectrum sensing is broadly divided into two categories, wideband and narrowband sensing. Narrowband sensing inspects one frequency channel whereas wideband sensing inspects more than one frequency at a time. The open research directions related to attacks targeting secure spectrum sensing and sharing has been discussed in [9]. The cooperative spectrum sensing is very useful in improving the reliability of spectrum sensing [10-12]. In a cooperative spectrum sensing approach, a central coordinator or fusion center that gathers the information from all the nearby cognitive nodes surrounded by the network. The fusion center examines the information and decides the channel accessibility that can and can't be utilized. The central node can also establish the various sensor nodes to measure the parameters like channel signal level, signal to noise ratio, channel bandwidth, and waiting time at different times. However, if central node failure occurs, the whole cooperative network will neglect to accomplish the spectrum sensing process. An optimal spectrum sensing nodes (SSN) selection assuring the sensing accuracy without disturbing the primary user can effectively reduce the energy utilization to prolong the network lifetime [13].

Channel decisions in the cognitive radio network can be characterized as the selection of an appropriate channel for the SU based on the quality of service required and quality of the available spectrum. The channel decision process involves three important tasks: spectrum characterization, spectrum selection, and cognitive radio reconfiguration [14]. After the identification of vacant spectrum bands through cognitive channel sensing, every channel is characterized depending upon the locally observed statistical information of the primary user. Depending upon the spectrum characterization, the next task is the selection of an appropriate spectrum band depending on the requirements of the secondary user. To achieve better communication the cognitive radio device must be able to reconfigure its transceiver parameters according to spectrum characteristics [15].

In today's era of digital communication, to overcome the complexity of the channel decision issues in cognitive radio technology, we need to apply the procedure that is easy to use and considered less complex to accomplish the desired solution. Incorporated formulas, adopted algorithms, and the use of scientific and legitimate methodologies prompt the advancement of decision-making strategies. Many more approaches for best channel selection through the available set of alternatives, each with different objectives in the cognitive radio environment is proposed [16].

The channel decision process based on an auction model can provide the guaranteed availability of spectrum, but the delay in the auction process is a major disadvantage of this auction scheme. In a learning-based scheme, the primary user's activity must be regular, and heterogeneous secondary user activity must be taken into consideration. Thus learning-based scheme may face new challenges [17].

In the next-generation wireless technology, the complexity of channel decision problems can be overcome by utilizing the more user-friendly method with less calculation to achieve the desired goal. When the selection criteria are decided, the MCDM approach is utilized. Multiple criteria decision making (MCDM) methodology mainly depends on two tasks; the construction of a weighted normalized decision matrix and the best alternative evaluation to every possible solution through any MCDM methods. Many MCDM methods like ELECTRE [18-19], AHP [20], VIKOR [21], SAW [14][23], and TOPSIS [14], etc. have been already proposed by many researchers for channel selection in cognitive radio technology. The detailed literature review of the above-mentioned algorithms is briefly discussed in table 1.

Confronting various criteria during channel decisions, we cannot rank the available channel by our inclination on a singular basis. In such cases, multiple objectives can be expressively taken into consideration. The key assignment of this research is to deliver an easy and certain channel decision method where more than one criterion is to be considered for channel selection appropriate in the cooperative cognitive network. The ultimate goal of the proposed work is to provide a proper explanation designed for typical decision-making issues using multi-objective optimization based on ratio system (MOORA). The MOORA algorithm was initially proposed by Brauers and Zavadskas in 2006 [24]. By utilizing the MOORA algorithm, decisions with moderate criteria can top within the order of available choices, which is not possible with linearly weighted objectives of the diverse channel by using another similar decision-making system [25-28].

May – June 2020
ISSN: 0193-4120 Page No. 1750 - 1760

The commitments of our work can be outlined as follows:

- Proposing a simple multiple criteria decision-making algorithm that can decide the available channel that matches the secondary user requirement based on the environmental condition in which it operates.
- Proposed a novel scheme where best channel choice with moderate objectives can rank in top.

The residual part of the projected work is prearranged as, the Sect. 2 will describe the selection of channel, the 3rd section will explain the MOORA method in detail. In Section 4, the analysis of performance is evaluated using the decision-making problem and simulation results. In Sect. 5 concluding remarks of the paper are given.

2. Channel Decision System

In numerous attribute decision-making methods, the objective of every cognitive node is to select the best-unused spectrum from a set of available alternatives of channels. To ensure the best quality of service by a cognitive radio network, every alternative is described with certain parameters like duty cycle, bandwidth, economic cost, and information rate. Based on these characteristics the channels are ranked and a decision will be taken. Figure 2. gives the system model of the proposed system in detail.

2.1. Fusion Centre

In a centralized cooperative spectrum sensing approach, there is a controlling node, a central coordinator or fusion center in the cooperative network collects characteristics information from all nearby cognitive radio nodes. The fusion center examines the information and decides the channel accessibility that can be utilized. The central node can also establish the various sensor nodes to measure the parameters like channel signal level, signal to noise ratio, channel bandwidth, and waiting time at different times. However, if central node failure occurs, the whole cooperative network will neglect to accomplish the spectrum sensing process.

2.2. Decision Parameters

Once the spectrum sensing process is done, the initial job of the channel decision process is to identify the spectrum holes. A set of parameters is calculated as per the requirements of the secondary user (SU). Such parameters may account potentially for selecting a particular spectrum hole. Here we propose bandwidth and information rate as benefit parameters, while duty cycle and economic cost as cost parameters.

2.2.1 Bandwidth:

Bandwidth is one of the essential considerations for channel decisions in the cognitive radio network. As per the IEEE 802.22 standard, expected spectrums that can be recycled as cognitive radio are in the range of 6MHz, 7 MHz and 8 MHz [29].

Table 1. MCDM Algorithm Brief Literature Review

Sr. No.	Authors and Title of Research	Description/Methodology	Merits/Demerits
1	K. Govindan and M. Jepsen, "ELECTRE: A comprehensive literature review on methodologies and applications", (2016). F. Bari and V. Leung, "Application of ELECTRE to Network Selection in a Heterogeneous Wireless Network environment." (2007)	The network alternatives are compared by the idea of concordance and no concordance in the ELECTRE method, which are proportions of fulfillment and disappointment of the decision-maker when all the available choices are compared with one another. In this way set of concordance (CSet) and discordance (DSet) are determined, where a CSet gives a set of alternatives which is superior to other alternatives that are being compared and a DSet gives a set of alternatives which is worst than other alternatives that are being compared.	• Decision-makers usually make use of this methodology because of its deterministic nature and a straightforward approach.

2	C Hernandez, C. Salgado, H. López, E. Rodriguez, “Multivariable algorithm for dynamic channel selection in cognitive radio networks.” (2015)	The AHP strategy is a calculation for multiple criteria decision making including quantitative and subjective criteria. The AHP method along with Fuzzy logic deals with the criteria assessments through a mathematical analysis that uses a range for the response instead of a precise number.	• The AHP algorithm along with the fuzzy logic technique permits the treatment of incorrect data. • This method is complicated to understand.
3	Cesar Hernández, Diego Giral, Fernando Santa “MCDM Spectrum Handover Models for Cognitive Wireless Networks”(2015)	In VIKOR technique the classification process among all the alternatives is processed in such a way that each alternative is evaluated according to each criterion and the ranking order can be decided through the comparison of the values that are closer to the ideal one.	• This method assumes that compromising is acceptable for conflicting resolution.
4	Rafael Gonzalez and Victor Ramos, “Spectrum Decision Mechanisms in Cognitive Radio Network.”(2018). C. Chandrasekar and K. Savitha, “Trusted Network Selection using SAW and TOPSIS Algorithms” (2011).	SAW (Simple Additive Weighting Method) is most likely the most popular and broadly utilized technique. The overall ranking of alternatives is figured as the weighted sum of all the alternative estimations.	• The advantage of the SAW method is it is very easy to understand. • Though it is very easy to understand, the SAW method has a drawback that this method does not differentiate between cost and benefit criteria, and thus during the process of normalization, the cost criteria must be converted into beneficial criteria.
5	Rafael Gonzalez and Victor Ramos, “Spectrum Decision Mechanisms in Cognitive Radio Network.”(2018)	TOPSIS is the most preferably used process for multi-criterion decision analysis. In this method of a set of alternatives is compared with weights for each criterion. After normalization, the separation measures among different alternatives, and each ideal alternative is determined using the Euclidian distance. Comparative relation with the ideal alternative is considered as the best score.	• The results show that TOPSIS has similar performance to that of the SAW method. • TOPSIS is a little complex method.

2.2.2 Information Rate:

The information rate is related to the capacity of bandwidth. As the higher bandwidth has more information rate. According to the IEEE 802.22 standard, the average spectral efficiency is 3 bits/sec/Hz [29].

The decision matrix is taken depends on the standard expected information rate in as below,

Information Rate = 18 Mbps for BW = 6MHz;
Information Rate = 21 Mbps for BW = 7MHz;
Information Rate = 24 Mbps for BW = 8 MHz;

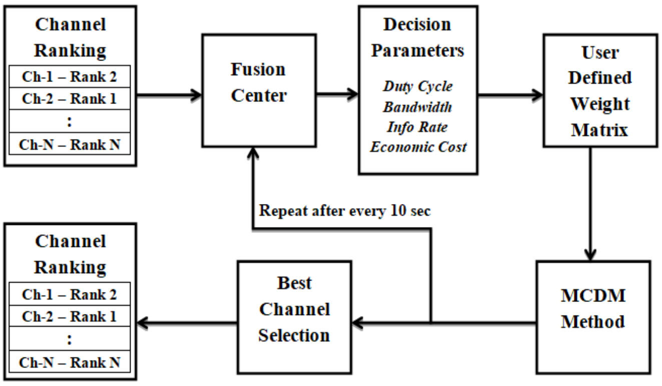

Figure 1. System Model

2.2.3 Economic Cost:

The economic cost is depending on the size of the spectrum. Thus for the 8 MHz band, the economic cost will be highest and for 6 MHz bands, it will be lowest.

2.2.3. Duty Cycle

It is defined as,

$$\%DC = \frac{T_{ON}}{T_{ON} + T_{OFF}} \times 100\%$$

Where T_{ON} is ON time and T_{OFF} is OFF time for the primary user.

The high percentage of DC values means the spectrum is utilized by the primary user most of the time whereas the lower percentage of DC values means the channel is available for use to the secondary user, which is highly required by the cognitive radio access system.

2.3. Weight Calculation

Based on the secondary user service requirement channel decision parameters have assigned different weights to decide the significance of each parameter. The sum of these weights must be equal to one.

$$\sum_{j=1}^{n} w_j = 1$$

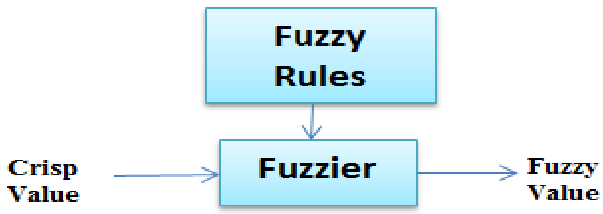

Figure 2. Fuzzy System

The level of importance of each parameter can be determined with the help of a fuzzy system. It consists of fuzzy rules and fuzzier. The fuzzy system is shown in the figure. 2. The output from the fuzzy inference system is always a fuzzy set irrespective of its input which can be a crisp value or fuzzy value.

The following input and output fuzzy sets are used as decision parameters for the secondary user. The sample rule is as shown in figure.3.

Bandwidth = {‘low’, ‘medium’, ‘high’}
With range {6 – 8 MHz},

Information Rate = {‘low’, ‘medium’, ‘high’}
With range {18 – 24Mbps},

Economic Cost= {‘low’, ‘moderate’, ‘high’}
With range {0 – 1},

Duty Cycle= {‘low’, ‘medium’, ‘high’}
With range {0 – 1}.

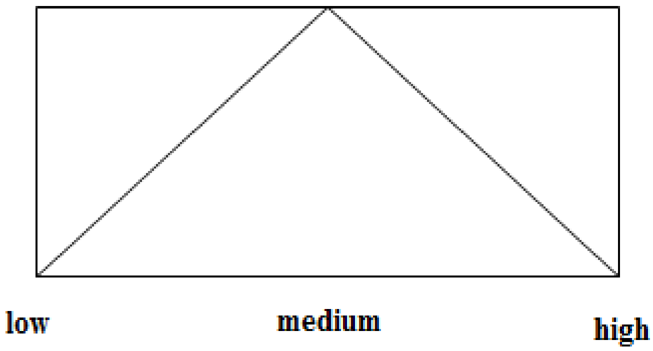

Figure 3. Sample Rule

2.4. MCDM Methods

2.4.1 SAW

It is also called a weighted sum method. This method is simple and most preferably used the MCDM method for decision-making technique. The best alternative is calculated by multiplying the normalized value of the alternative to the user-defined weight to of that criterion for each alternative.

Step 1: Normalize the decision matrix using Eq 2.1 and Eq 2.2.

May – June 2020
ISSN: 0193-4120 Page No. 1750 - 1760

$$V_{ij} = \frac{x_{ij}}{xj^{\max}}$$
(2.1)

$$V_{ij} = \frac{x_j^{\min}}{x_{ij}}$$
(2.2)

Step 2: Alternative score is calculated by using the below equation:

$$A_i = \sum_{j=1}^{n} w_j * V_{ij}$$
(2.3)

Step 3: Among the available, the best alternative score is calculated by using the below equation:

Best alternative = $\max_i A_i$.

2.4.2 TOPSIS

K. Yoon and C. Hwang initially present the TOPSIS method in 1981 [24]. This method uses the relative efficiency of alternatives based on similarity to a positive ideal solution and similarity to a negative solution with the worst values. Following are the steps of TOPSIS algorithm,

Step 1: The normalized decision matrix rij obtained from xij (decision matrix) using Eq 2.4.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$
(2.4)

Step 2: The normalize weighted decision matrix vij is constructed using Eq 2.5, where wj be user-defined weight matrix :

$$v_{ij} = w_j * r_{ij}$$
(2.5)

Step 3: Verify positive as well as negative principle alternative through the Eq 2.6 and Eq 2.7:

$$A^+ = \{(\max_{i\in M} v_{ij} \mid j \in J), (\min_{i\in M} v_{ij} \mid j \in J')\}$$
(2.6)

And

$$A^- = \{(\min_{i\in M} v_{ij} \mid j \in J), (\max_{i\in M} v_{ij} \mid j \in J')\}$$
(2.7)

Where J is the set of benefit parameters, and J' is the set of cost parameters.

Step 4: The disjointing computation among various alternatives of positive and negative is calculated as Euclidian distance by using the Eq 2.8 and Eq. 2.9

$$d_i^+ = \sqrt{\sum_{j\in N} \left| v_i^+ - v_{ij} \right|}$$
(2.8)

And

$$d_i^- = \sqrt{\sum_{j\in N} \left| v_i^- - v_{ij} \right|}$$
(2.9)

Step 5: The ideal alternative relation is given by:

$$c_i = \frac{d_i^-}{\left(d_i^+ + d_i^-\right)}$$
(2.10)

A set of alternatives can now be preferably ranked in descending order of closeness Ci.

3. Moora Method (Proposed Method)

In the Moora method, matrix normalization is performed using four different techniques. A_i are unformulated variables representing the available channel alternatives, C_j are non-formalized variables representing the criteria, and a_{ij} representing the evaluation of alternatives according to the criteria obtained from actual data or expertly based on selected scales of assessment.

A_i Where, $i = 1, 2\ldots m$ and

May – June 2020
ISSN: 0193-4120 Page No. 1750 - 1760

C_j Where, $j = 1, 2 \dots n$;

Thus Decision matrix D is given below as,

$$D = [a_{ij}]_{m \times n} \quad (3.1)$$

Step 1: Normalize the decision matrix

Dimensionless numbers x_{ij}, representing the normalized response is determined by using the normalization technique shown in equation 3.2 depending upon the benefit and cost criteria.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (3.2)$$

Step 2: Determine the normalized weighted matrix

It is determined by using normalized response and weight of the criteria as:

$$v_{ij} = x_{ij} * w_j \, . \quad (3.3)$$

Step 3: Determine the overall ranking

To determine the overall ranking, the max (beneficial) and min (cost) criteria is calculated as:

Max (beneficial) = (+1) and

Min (cost) = (-1);

$$sg_j = signC_j ; \; j = 1, \dots, n;$$

$$\text{Thus, } sg_j = \{\pm 1\}; \quad (3.4)$$

$$Q_i = \sum_{j=1}^{n} sg_j \cdot v_{ij}; \quad (3.5)$$

Step 4: Determine the best alternative

Thus, Best alternative = $\max_i Q_i$;

4. Performance Analysis

Suppose there are four vacant channels A1, A2, A3, A4 as an alternative, and X1, X2, X3, X4 are the criteria; bandwidth, duty cycle, economic cost and information rate respectively to be considered for channel selection. The decision issue can be briefly communicated in the decision matrix, where the capacities of every channel are exhibited. The economic cost and duty cycle are scaled utilizing a similar unit separately. A1 has the highest bandwidth and information rate. A4 has the lowest duty cycle and economic cost. A2 has medium bandwidth, duty cycle, economic cost, and information rate [30].

$$D = \begin{array}{c} \\ A1 \\ A2 \\ A3 \\ A4 \end{array} \begin{array}{c} \begin{array}{cccc} \boldsymbol{X1} & \boldsymbol{X2} & \boldsymbol{X3} & \boldsymbol{X4} \end{array} \\ \begin{bmatrix} 8 & \text{low} & \textit{high} & 24 \\ 7 & \text{medium} & \textit{medium} & 21 \\ 7 & \text{high} & \textit{medium} & 21 \\ 6 & \text{low} & \textit{low} & 18 \end{bmatrix} \end{array}$$

4.1 Equally Weighted Parameters

The presentation of algorithms as SAW, MOORA, and TOPSIS for channel assessment in CRN is as shown in Table 2, considering the similar significant weight of every attributes for the secondary users. Figure 4 shows that the algorithms SAW, TOPSIS, and MOORA gives an analogous presentation with an economic cost, bandwidth, duty cycle, and information rate.

Table 2. Performance comparison of MCDM algorithm with equally weighted parameters

Algorithm	**Bandwidth**	**Duty Cycle**	**Economic Cost**	**Information Rate**
MOORA	6 MHz	Low	Low	18Mbps
SAW	6 MHz	Low	Low	18Mbps
TOPSIS	6 MHz	Low	Low	18Mbps

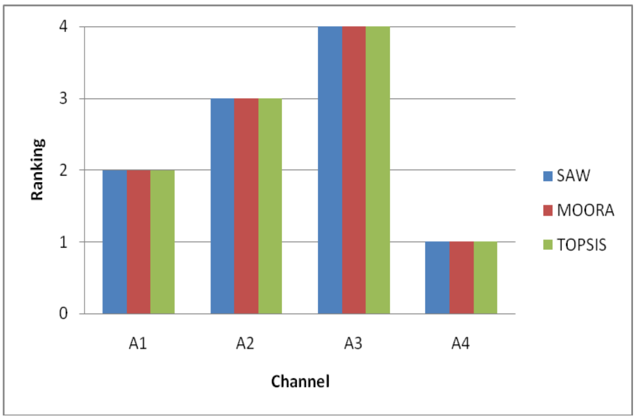

Figure 4. Channel ranking of MCDM algorithm for equally weighted parameters

TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 1750 - 1760

4.2 Bandwidth Based Decision

For certain applications, spectrum bandwidth is considered to be as important parameters to the secondary user. Therefore a higher weight to bandwidth parameter is assigned. Thus a method that selects spectrum with higher bandwidth will be considered as the best choice within available spectrum choices for a secondary user. Figure 5 shows the performance of SAW, TOPSIS, and MOORA algorithms for bandwidth-based channel decisions in the cognitive radio network. In table 3, we summarize the results where we compare the criteria for each algorithm. Here it can be seen that SAW algorithms perform better than MOORA and TOPSIS in bandwidth and information rate.

Table 3. Performance comparison of MCDM algorithm for bandwidth-based decision weight parameters.

Algorithm	Bandwidth	Duty Cycle	Economic Cost	Information Rate
MOORA	6 MHz	Low	Low	18Mbps
SAW	8 MHz	Low	High	24Mbps
TOPSIS	6 MHz	Low	Low	18Mbps

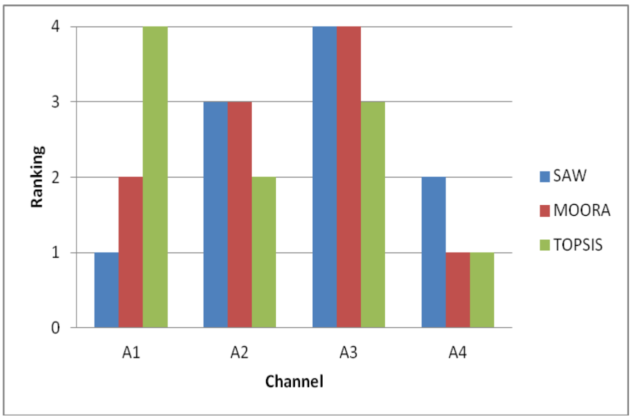

Figure 5. Channel ranking of MCDM algorithm for bandwidth-based decision weight parameters.

4.3 Duty Cycle Based Decision

Here we considered that several secondary cognitive users may necessitate accessing the spectrum for a longer time. Therefore a higher weight is assigned to the duty cycle parameter. Thus an algorithm that selects the lowest duty cycle will be considered as the best choice within available spectrum choices for a secondary user. Figure 6 shows the presentation of SAW, MOORA, and TOPSIS and algorithms for channel decisions in the cognitive radio network. In table 4, we summarize the results where we compare the criteria for each algorithm. For duty cycle based decision it can be seeing that the MOORA and TOPSIS algorithm exhibit the best performance in the duty cycle, and economic cost than the SAW algorithm.

Table 4. Performance comparison of MCDM algorithm for duty cycle based decision weight parameters.

Algorithms	Bandwidth	Duty Cycle	Economic Cost	Information Rate
MOORA	6MHz	Low	Low	18Mbps
SAW	7MHz	Medium	Medium	21Mbps
TOPSIS	6MHz	Low	Low	18Mbps

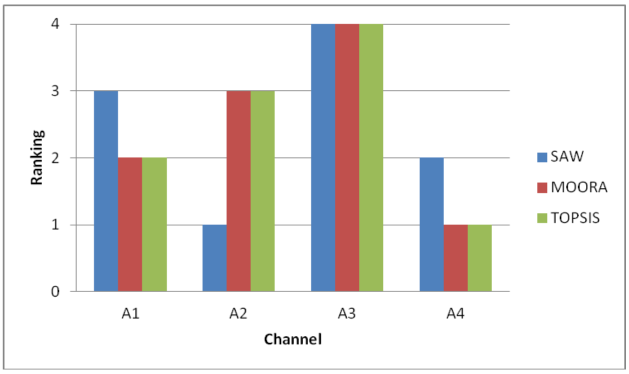

Figure 6. Channel ranking of MCDM algorithm for duty cycle based decision weight parameters.

4.4 Bandwidth and Duty Cycle Based Decision

Here we considered that some secondary cognitive users might be accessing the spectrum for a longer time and with higher bandwidth. Therefore a higher weight is assigned to bandwidth and duty cycle parameters. Thus an algorithm that selects the lowest duty cycle and higher bandwidth will be considered as the best choice within available spectrum choices for a secondary user. Figure 7 gives the presentation of all algorithms for channel selection in the cognitive radio network. In table 5, we summarize the results where we compare the criteria for each algorithm. For bandwidth and duty cycle based decision it can be seen that the MOORA and SAW algorithm outperformed TOPSIS in bandwidth, duty cycle, and information rate.

May – June 2020
ISSN: 0193-4120 Page No. 1750 - 1760

Table 5. Performance comparison of MCDM algorithm for bandwidth and duty cycle based decision weight parameters.

Algorithm	Bandwidth	Duty Cycle	Economic Cost	Information Rate
MOORA	8MHz	Low	High	24Mbps
SAW	8MHz	Low	High	24Mbps
TOPSIS	6MHz	Low	Low	18Mbps

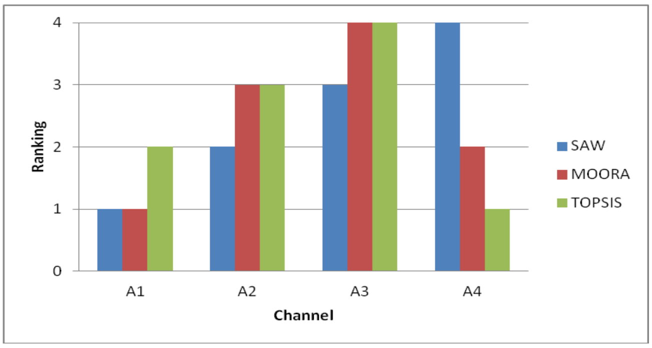

Figure 7. Channel ranking of MCDM algorithm for bandwidth and duty cycle based decision weight parameters.

4.5 The Economic Cost-Based & Duty Cycle Decision

Table 6. Performance comparison of MCDM algorithm for duty cycle and economic cost-based decision weight parameters.

Algorithm	Bandwidth	Duty Cycle	Economic Cost	Information Rate
MOORA	6MHz	Low	Low	18Mbps
SAW	7MHz	Medium	Medium	21Mbps
TOPSIS	8MHz	Low	High	24Mbps

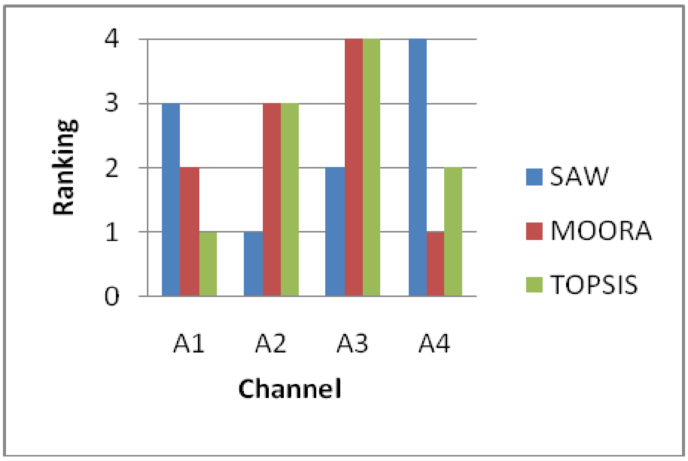

Figure 8. Channel ranking of MCDM algorithm for duty cycle and economic cost-based decision weight parameters.

Here, we considered that a few secondary cognitive users may necessitate accessing the spectrum for a long time with the cheapest service. Consequently, a higher weight is assigned to the duty cycle and the economic cost parameter. Thus an algorithm that selects the lowest duty cycle and cheapest service will be considered as the best choice within available spectrum choices for a secondary user. Figure 8 shows the presentation of all said algorithms for channel selection in the cognitive radio network. In table 6, we summarize the results where we compare the criteria for each algorithm. For the duty cycle and economic cost-based decision, it can be seen that the MOORA algorithm outperformed TOPSIS and SAW in the duty cycle and economic cost.

5. Conclusion

In the present era of wireless communication, the evolution of the decision-making system allows cognitive radio experts to access the available channel parameters and facilitate the spectrum decision process. The simulation results and analysis shows that the proposed MOORA algorithm outperforms the other similar algorithm in terms of channel utilization and complexity.

From the simulation results, some fundamental conclusions can be drawn.

1. In MOORA, decisions with a moderate objective can top within an order of available choices, which is not possible with linearly weighted objectives of the diverse channel by using other similar decision-making methods.
2. Consideration of conflicting objectives is conceivable.
3. The results obtained in table 5 and table 6 shows that the MOORA method gives better results than the SAW and TOPSIS algorithm where more than one objective is considered for channel decision.
4. The result obtained here is even though based on simulations of theoretical structures, it can be concluded that MOORA is effective and can be used practically when statistics related to different objectives are available from fusion canter.

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May – June 2020
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