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DYNAMIC SPECTRUM SHARING IN COGNITIVE RADIO USING FUZZY LOGIC SYSTEM

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ABSTRACT

Dynamic Spectrum Allocation is a solution to the problem of spectrum underutilization to harness the unused spectrum potentially and opportunistically. In this scheme a group of four quality parameters i.e. efficiency of spectrum use by unlicensed or secondary user, its mobility, its distance from primary (licensed) user and its signal strength have been used to make the spectrum allocation decision. The four parameters have three membership functions each which are based on the linguistic knowledge. Therefore, there are a total of 81 rules which govern the output of the fuzzy inference system. The output of this system gives the possibility of accessing the spectrum for secondary users. Obviously the user with highest possibility will be assigned the available spectrum band.

KEYWORDS: Cognitive Radio, Fuzzy Logic System, Opportunistic Spectrum Access, Knowledge-Based Spectrum Access Scheme

I. INTRODUCTION

The latest challenge that our wireless communication technology is facing today is the problem of overcrowded frequency spectrum to such an extent that the available radio spectrum is exhausted and no more vacant bands are available for users. Also the practice of allocating a dedicated spectrum to users called primary users (static allocation) is very inflexible and inefficient as the spectrum remains underutilized. Hence a new concept dynamic allocation of spectrum has emerged in recent years which allow unlicensed users to share the spectrum with the existing licensed users in an opportunistic way without causing interference to the latter. This paradigm for wireless communication is called Opportunistic Spectrum Access (OSA) and the new research field emerging as a consequence of this concept is called Cognitive Radio [1]. Cognitive Radio technology refers to the intelligent wireless technology which has the capability to sense or capture the information from its radio environment and adapt to it accordingly. Its objective is-highly reliable communication with efficient utilization of radio spectrum without causing interference to the primary user.[1-6]. Whenever a spectrum band is unutilized by the primary user it is called a spectrum hole or white spaces. These holes can be used by secondary users for communication. The primary users are privileged to access the spectrum at any time, but secondary users have to sense the environment, and then opportunistically utilize the available spectrum [7]

Accordingly they need to adapt to the local behaviors of the primary users and vacate the spectrum immediately whenever the presence of primary user is detected, which is called spectrum handoff [8, 9].

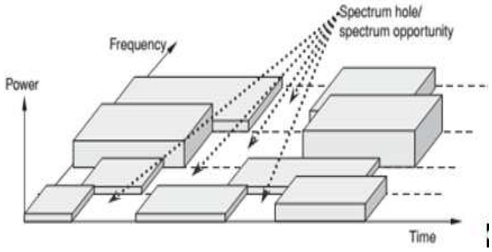


Figure 1: The Spectrum Hole Concept

Due to complexity, modularity, information imprecision and mobility issues the design of Cognitive radio becomes a very challenging task[10]. The opportunistic spectrum access encounters several challenges such as: To access the spectrum opportunistically without causing interference to the primary user as well as other secondary users, to sense and identify the radio environment and coordinate its use, to design a priority mechanism, to facilitate this access scheme to be in accordance with regulatory policies [11,12]. In the research literature on the opportunistic spectrum access, spectrum allocation using a graph coloring algorithm is proposed but mobility of the secondary users is not considered by Zheng [13]. Some work using game theoretical analysis has been performed by Nie and Comaniciu [14] to find out the strategies for spectrum sharing. The opportunistic spectrum access via periodic sensing has also been discussed by Zhao, et al [15], where framework of constrained Mark ovdecision processes is presented, which yields the negligible loss of throughput but the presence of more than two secondary users is not considered. The concept of opportunistic spectrum access and the listen-before-talk approach leads to overlooked spectrum an opportunity which has been discussed by Zhao [16]. For enhancing the performance of cognitive radio, fuzzy logic based scheme is developed by Wanbin and Dong [17], where spectrum handoff issue with efficient utilization of spectrum bandwidth is discussed. The efficient decision making in the cognitive radio by fuzzy logic is also discussed by Matinmikko et al [18], which explored the applications of fuzzy logic in telecommunication. The intelligent handoff algorithms and access scheme by fuzzy logic system for fourth generation network is also discussed in [19]. Coexistence beacon protocol (CBP) is proposed by using fuzzy logic to improve resource utilization and fairness in cognitive radio as well as mobility issue is also discussed in [20]. Opportunistic spectrum access by using fuzzy logic has been discussed by Q. Liang et al [21], the access method developed by them uses three descriptors or antecedents,

Which are spectrum utilization efficiency, degree of mobility of secondary user and distance of secondary users from the primary user, but the signal strength of secondary user has not been considered which is affected by multipath and fading effects, making the system highly unreliable these limitations have inspired us to work in this research area. We have used four antecedents, which are spectrum utilization efficiency of the secondary user, its degree of mobility, its distance to the primary user and signal strength of secondary users to design this method of spectrum access. These four antecedents are governed by a set of 81 “If-Then” fuzzy rules based on linguistic knowledge and the consequence of this FLS gives the possibility of each secondary user to access the spectrum, the user with the greatest possibility will be assigned the available spectrum band.

When an input is applied to the FLS, the inferenceengine computes the output set corresponding to each rule. The defuzzifier then computes a crisp output from these rule output sets. Consider a p-input and 1-outputFLS, using singleton fuzzification, center-of-setsdefuzzification and “IF-THEN” rules of the form:

R_l : IF x1 is F1 l and x2 is F2 l and . . . and xp is Fp_l ; THEN y is Gl

Assuming singleton fuzzification is used, when an inputx’ = {x1’, x_2’, x_3’……x_p’} is applied, the degree of firing corresponding to the lth rule is computed as [21].

$$\mu_{f_1^l}\left(x_1^{'}\right)*\mu_{f_2^2}\left(x_1^{'}\right)*.....*\mu_{f_p^l}\left(x_p^{'}\right)=\mathrm{T}_{i=1}^{p}\mu_{f_i^l}\left(x_i^{'}\right) \tag{1}$$

Whereμ and *T* both indicate the chosen t-norm [22].Out of several kinds of defuzzifier. We have emphasized for illustrative purposes, on the center-of-sets defuzzifier in this paper. It computes a crisp output for the FLS by first computing the centroid, *CGl*; of every consequent set *Gl*, and, then computing a weighted average of these centroids. The weight corresponding to the lth rule consequent centroid is the degree of firing associated with the Equation (1)

$$y_{\cos}\left(x^{'}\right)=\frac{\sum_{l=1}^{M} c_{G^l} T_{i=1}^{p}\mu_{F_i^l}\left(x_i^{'}\right)}{\sum_{l=1}^{M} T_{i=1}^{p}\mu_{F_i^l}\left(x_i^{'}\right)} \tag{2}$$

Where *M* is the number of rules in the fuzzy logic system

The remaining sections of this paper have been organized as follows-

Section II gives proposed system model. Section III describes input parameters or antecedents for opportunistic spectrum access. Section IV gives the linguistic variances representation of inputs. Section V contains the simulation results and discussion. Conclusion and future work are mentioned in the final section.

II. PROPOSED SYSTEM MODEL

The proposed FLS model is as shown in Figure 1 where the system operates with four inputs and one output as shown below:

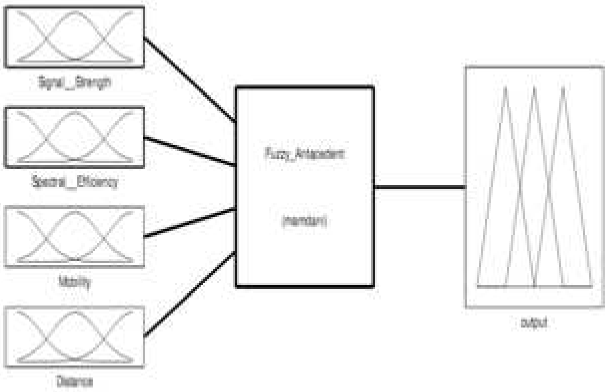


Figure 2: Proposed FLS Model Structure

Flow chart for this proposed scheme is asfollow-

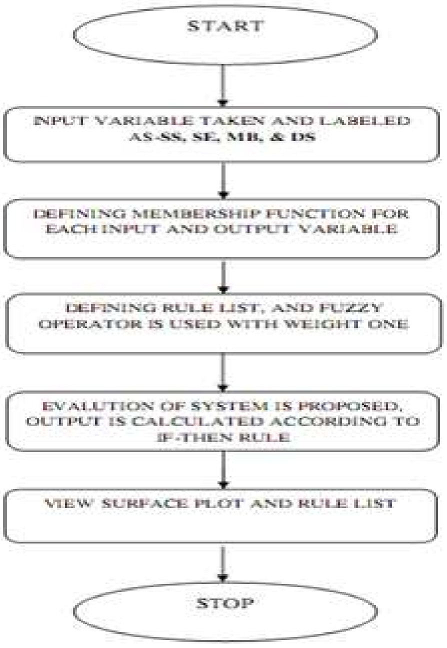


Figure 3: Flow Chart for Proposed Scheme of Opportunistic Spectrum Access

III. INPUT PARAMETERS OR ANTECEDENTS FOR OPPORTUNISTIC SPECTRUM ACCESS

The fuzzy logic system modeled for the opportunistic spectrum access in cognitive radio networks takes the decision of selecting the best suitable secondary user as it is very simple, flexible and easy to understand .Here we have given four inputs to the fuzzifier. Based on mathematical and reasoning process the inference engine using these four antecedents takes the decision and gives the output. This output is governed by the rules at inference engine to select the secondary user with highest probability allowed to access the spectrum without causing interference or violating the regulation policy. The following are the four parameters used by the FLS

- **Parameter 1:** Spectrum utilization efficiency,
- **Parameter 2:** Degree of mobility,
- **Parameter 3:** Distance to the primary user and
- **Parameter 4:** Signal strength of secondary users.

The conditional statements consisting of the “IF-THEN” rules have been taken. If the secondary user is having farthest distance to the primary user or the secondary user has maximum spectrum utilization efficiency, then the probability of that SU being chosen is high provided it creates no interference to the PU while it accesses the spectrum, mobility of the secondary user is low and the signal strength is high. This rule based approach uses we combination of theabove four antecedents to find appropriate solutions to opportunistic spectrum access.

- **Spectrum Utilization Efficiency** and signal strength are the main two important parameters to be considered for the opportunistic spectrum access schemes. Spectrum utilization efficiency □s is defined as the ratio between the spectrum band which will be used by the secondary user and the available band [21].

$$\eta_s = \frac{BW_s}{BW_a} \times 100\% \tag{3}$$

Where BW$_s$ is the spectrum bandwidth which is used by the secondary user and BW$_a$ is the total available bandwidth.

- **Mobility** of the secondary user also is an important parameter to be considered in the design. When the secondary user is moving at a velocity v m/s, it causes the Doppler shift [21, 22].

$$f_d = \frac{v \cos\theta}{c} f_c \tag{4}$$

Where f dis the Doppler shift, θ is the arrival angle of the received signal relative to the direction of motion, c is the wave velocity, and fc is carrier frequency. The detection of signal of the primary users as well as other secondary user can be highly affected by the mobility of the secondary user. Hence if the secondary user does not detect the primary signal, it will interpret the channel as a free channel or spectrum as vacant

This will cause interference to the users already using the channel, i.e., the signal transmitted by the secondary user will interfere with the signal .that the primary user is trying to decode. This situation is often referred as hidden node problem [23].

- **Distance**between the secondary user and the primary user is the third parameter to be considered. The location of primary users can be obtained via GPS or any other similar technology. If the location of the primary user is unknown we can consider signal-to noise ratio (SNR) as a proxyfordistance [21]. Suppose distance between the PU$_i$and the SU$_i$ is diand power gain between them is P1$_i$, and g(di), is a continuous, nonnegative, strictly decreasing function of di defined on the interval [0;1]

  Then $\Upsilon_{si} = 10\log(\frac{P_{li}g(d_i)}{\sigma_1^2})$ (5)

  WhereΥ_{si} and σ_1^2 are the SNR and noise power measured at the SU$_i$ respectively.

- **Signal Strength** is one of the as four antecedents. Signal to noise ratio (SNR) detection of secondary users provides the knowledge about the signal strength of secondary users. Signal strength gives us the information regarding the quality of signal and effects of fading or Doppler Shift on the signal. The signal strength of secondary user is detected and secondary user with high signal is given preference.

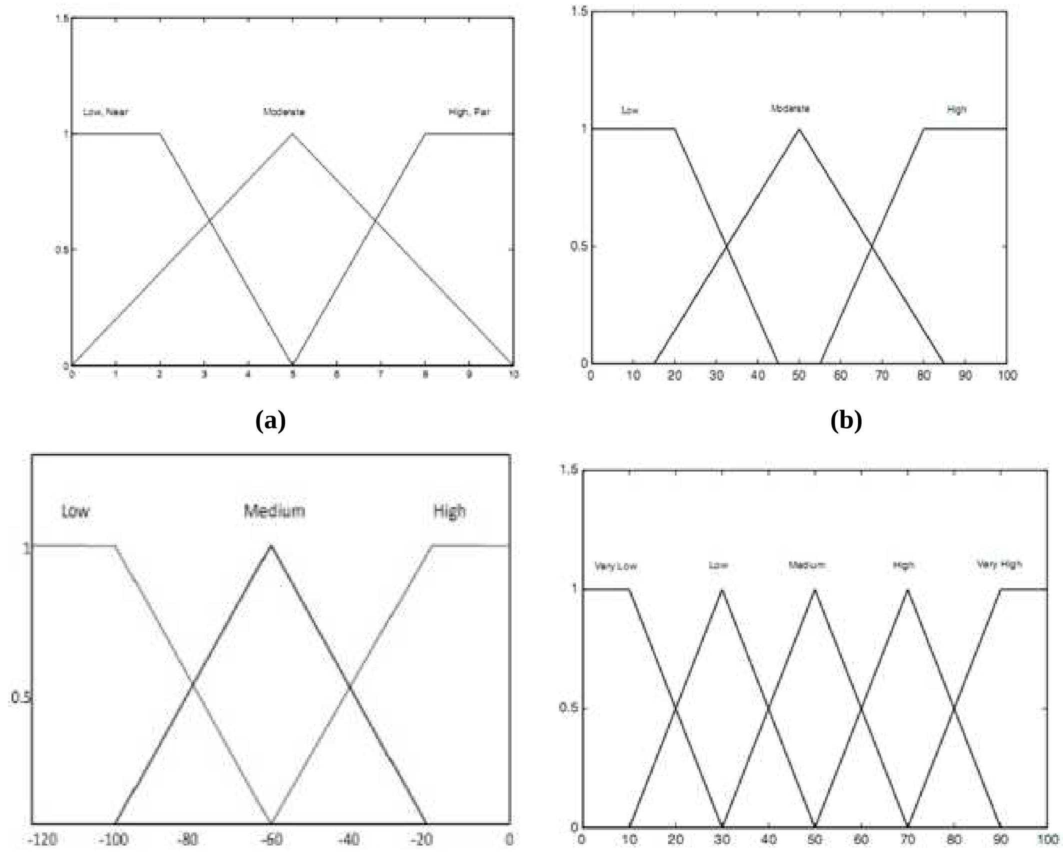
Using these four parameters a rule base of 81 rules has been formed with a single output for each rule. The centroid of all the responses for each rule are then averaged and instead of taking rule consequent centroid this average has been taken as the output. Doing this leads to rules that have the following form: Rl: IF spectrum utilization efficiency of the secondary user (x1) is F1l, and its degree of mobility(x2) is F21, its distance to the primary user (x3) is F31 and signal strength of the secondary (x4)is F41, THEN the possibility (y) that this secondaryuser is chosen to access the available spectrum is Cavg, from (2) [21]

$$y_{\cos}\left(x'\right) = \frac{\sum_{l=1}^{M} c_{G^l} T_{i=1}^{p} \mu_{F_i^l}\left(x_i'\right)}{\sum_{l=1}^{M} T_{i=1}^{p} \mu_{F_i^l}\left(x_i'\right)}$$

Where l =1; 2; . . . 81;

IV. LINGUISTIC VARIANCES REPRESENTATION OF INPUTS

The linguistic variances used to represent the spectrum utilization efficiency, Signal strength and degree of mobility are divided into three levels: low, moderate, and high while we use three levels, which are near, moderate, and far to represent the distance. The consequence, that is, the possibility that the secondary user is chosen to access the spectrum is divided into five levels which are very low, low, medium, high and very high. We use trapezoidal membership functions (MFs) to represent near, low, far, high, very low and very high, and triangle membership functions to represent moderate, low, medium and high [24-26]. Membership functions are described in Figure 2[21]. Since we have four antecedents, we need to set up 3^4= 81 rules for this FLS. Then, we design rules, which will be used to take decision, according to rules as follows:



(a) **(b)**

(b) **(d)**

(a) is spectrum efficiency,

(b) indicates mobility and distance,

(c) represents signal strength and,

(d) Represents output.

Figure 4: Descriptors and Output in Linguistic Variables Form, Where

“IF the spectrum utilization efficiency of the secondary user is moderate, its degree of mobility is low, its distance to the primary user is far and signal strength is high THEN the possibility that this user is selected to access the spectrum is ---- “ here Cavgcan be calculated through (6):

$$C_{avg}^{l} = \frac{\sum_{i=1}^{l} w_i^l c^l}{\sum_{i=1}^{l} w_i^l} \tag{6}$$

Since we chose a single consequent for each rule to form a rule base, we averaged the centroids of all there sponses for each rule and used this average in place of the rule consequent centroid. This method is the most popular de fuzzification method which returns the center of area under the curve. Doing this leads to rules that have the following form: For every input (x_1, x_2, x3, $x_{4)}$, the output or consequences y ((x_1, x_2, x_3, x_4), of the designed FLS is computed, from (6) as

$$y\left(x_1,x_2,x_3,x_4\right) = \frac{\sum_{l=1}^{27} \mu_{F_1^l}\left(x_1^{'}\right)\mu_{F_2^l}\left(x_2^{'}\right)\mu_{F_3^l}\left(x_3^{'}\right)\mu_{F_4^l}\left(x_4^{'}\right)c_{avg}^{l}}{\sum_{l=1}^{27} \mu_{F_1^l}\left(x_1^{'}\right)\mu_{F_2^l}\left(x_2^{'}\right)\mu_{F_3^l}\left(x_3^{'}\right)\mu_{F_4^l}\left(x_4^{'}\right)} \tag{7}$$

The rules are defined based on the linguistic knowledge center of sets de fuzzification method is used to calculate the output, according to which priority to access the spectrum is made while maintain the seamless communication [21].

V. SIMULATION RESULTS AND DISCUSSION

We recognize that (6) can be represented in a 2-Dplot, which has been shown by Figure 3, where wefixed the mobility at moderate, varying distance at step size of two and consider the three cases of signal strength, which has been kept as low, moderate and high with varying efficiency and made it into 2-d plot. Figure 3(b), 3(c) and 3(d) represents the opportunistic spectrum access decision plot for the cognitive user for these three cases respectively. From Figure 3, we seeclearly that, at the same spectrum utilization efficiency and mobility degree, secondary users farther from the primary user have higher chance to access the spectrum. We also show the surface of three antecedent case for comparison purpose when signal strength has not been considered in Figure 3(a) we recognize that (6) is observed in a 4-D surface. Since it is impossible to plotvisually, we fix one of four variables. More specifically, we fixed mobility of the primary user. We have taken the three descriptor cases where signal strength of SUs is not considered for comparison purpose [21]. Mobility is fixed as moderate shown Figure 4(a), where distance and spectrum efficiency are varying but signal strength of secondary user is not considered. Similarly for observations, in our scheme we made the three cases as shown in figure 4(b), 4(c) and 4(d). Mobility is fixed as moderate and distance, spectrum efficiency are varying, but in first case shown in Figure 4(b), signal strength is kept as low, where in Figure 4(c), signal strength is considered as moderate, and in Figure 4(d)signal strength is considered as high.

VI. SIMULATION RESULTS AND DISCUSSIONS

Table 1: Rules for Proposed Fuzzy Logic Structure

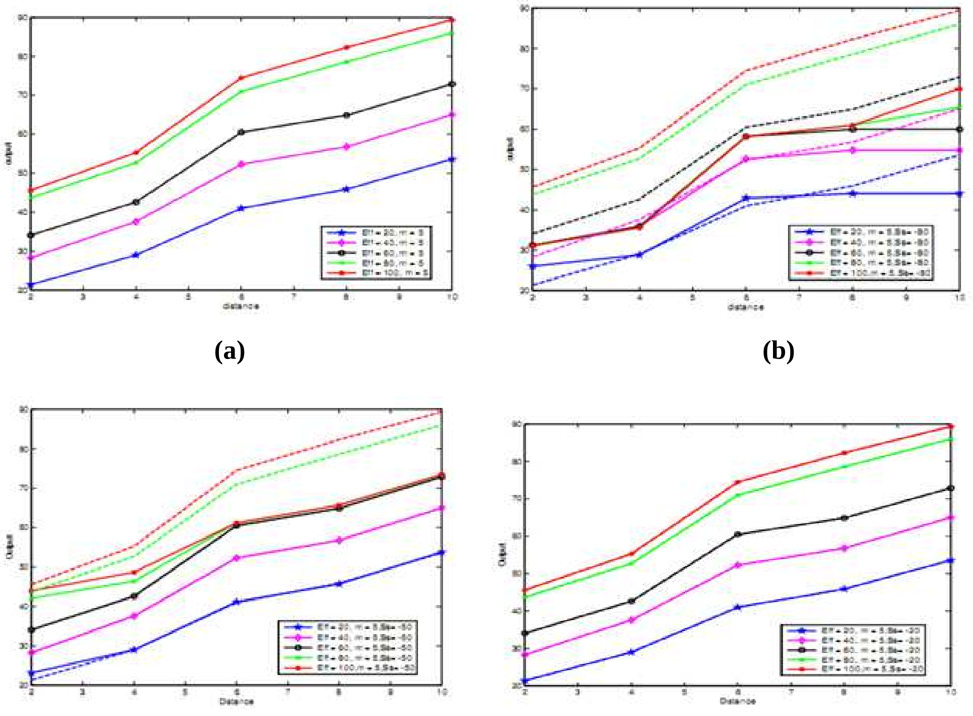
Rule#	Antecedent 1	Antecedent 2	Antecedent 3	Antecedent 4	Consequence
1.	LOW	LOW	LOW	LOW	VERY LOW
2.	LOW	LOW	LOW	MEDIUM	LOW
3.	LOW	LOW	LOW	HIGH	LOW
4.	LOW	LOW	MEDIUM	LOW	VERY LOW
5.	LOW	LOW	MEDIUM	MEDIUM	LOW
6.	LOW	LOW	MEDIUM	HIGH	LOW
7.	LOW	LOW	HIGH	LOW	VERY LOW

Table 1: Contd.,

8.	LOW	LOW	HIGH	MEDIUM	LOW
9.	LOW	LOW	HIGH	HIGH	LOW
10.	LOW	MEDIUM	LOW	LOW	VERY LOW
11.	LOW	MEDIUM	LOW	MEDIUM	LOW
12.	LOW	MEDIUM	LOW	HIGH	MEDIUM
13.	LOW	MEDIUM	MEDIUM	LOW	VERY LOW
14.	LOW	MEDIUM	MEDIUM	MEDIUM	MEDIUM
15.	LOW	MEDIUM	MEDIUM	HIGH	MEDIUM
16.	LOW	MEDIUM	HIGH	LOW	VERY LOW
17.	LOW	MEDIUM	HIGH	MEDIUM	LOW
18.	LOW	MEDIUM	HIGH	HIGH	LOW
19.	LOW	HIGH	LOW	LOW	VERY LOW
20.	LOW	HIGH	LOW	MEDIUM	MEDIUM
21.	LOW	HIGH	LOW	HIGH	MEDIUM
22.	LOW	HIGH	MEDIUM	LOW	VERY LOW
23.	LOW	HIGH	MEDIUM	MEDIUM	MEDIUM
24.	LOW	HIGH	MEDIUM	HIGH	HIGH
25.	LOW	HIGH	HIGH	LOW	VERY LOW
26.	LOW	HIGH	HIGH	MEDIUM	MEDIUM
27.	LOW	HIGH	HIGH	HIGH	MEDIUM
28.	MODERATE	LOW	LOW	LOW	VERY LOW
29.	MODERATE	LOW	LOW	MEDIUM	LOW
30.	MODERATE	LOW	LOW	HIGH	LOW
31.	MODERATE	LOW	MEDIUM	LOW	VERY LOW
32.	MODERATE	LOW	MEDIUM	MEDIUM	LOW
33.	MODERATE	LOW	MEDIUM	HIGH	MEDIUM
34.	MODERATE	LOW	HIGH	LOW	VERY LOW
35.	MODERATE	LOW	HIGH	MEDIUM	LOW
36.	MODERATE	LOW	HIGH	HIGH	LOW
37.	MODERATE	MEDIUM	LOW	LOW	VERY LOW
38.	MODERATE	MEDIUM	LOW	MEDIUM	LOW
39.	MODERATE	MEDIUM	LOW	HIGH	MEDIUM
40.	MODERATE	MEDIUM	MEDIUM	LOW	VERY LOW
41.	MODERATE	MEDIUM	MEDIUM	MEDIUM	MEDIUM
42.	MODERATE	MEDIUM	MEDIUM	HIGH	HIGH
43.	MODERATE	MEDIUM	HIGH	LOW	VERY LOW
44.	MODERATE	MEDIUM	HIGH	MEDIUM	LOW
45.	MODERATE	MEDIUM	HIGH	HIGH	MEDIUM
46.	MODERATE	HIGH	LOW	LOW	LOW
47.	MODERATE	HIGH	LOW	MEDIUM	HIGH
48.	MODERATE	HIGH	LOW	HIGH	VERY HIGH
49.	MODERATE	HIGH	MEDIUM	LOW	LOW
50.	MODERATE	HIGH	MEDIUM	MEDIUM	MEDIUM
51.	MODERATE	HIGH	MEDIUM	HIGH	HIGH
52.	MODERATE	HIGH	HIGH	LOW	VERY LOW
53.	MODERATE	HIGH	HIGH	MEDIUM	MEDIUM
54.	MODERATE	HIGH	HIGH	HIGH	HIGH
55.	HIGH	LOW	LOW	LOW	VERY LOW
56.	HIGH	LOW	LOW	MEDIUM	LOW
57.	HIGH	LOW	LOW	HIGH	MEDIUM
58.	HIGH	LOW	MEDIUM	LOW	VERY LOW
59.	HIGH	LOW	MEDIUM	MEDIUM	LOW
60.	HIGH	LOW	MEDIUM	HIGH	MEDIUM
61.	HIGH	LOW	HIGH	LOW	VERY LOW
62.	HIGH	LOW	HIGH	MEDIUM	LOW

Table 1: Contd.,

63.	HIGH	LOW	HIGH	HIGH	MEDIUM
64.	HIGH	MEDIUM	LOW	LOW	VERY LOW
65.	HIGH	MEDIUM	LOW	MEDIUM	MEDIUM
66.	HIGH	MEDIUM	LOW	HIGH	HIGH
67.	HIGH	MEDIUM	MEDIUM	LOW	VERY LOW
68.	HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM
69.	HIGH	MEDIUM	MEDIUM	HIGH	HIGH
70.	HIGH	MEDIUM	HIGH	LOW	VERY LOW
71.	HIGH	MEDIUM	HIGH	MEDIUM	LOW
72.	HIGH	MEDIUM	HIGH	HIGH	HIGH
73.	HIGH	HIGH	LOW	LOW	LOW
74.	HIGH	HIGH	LOW	MEDIUM	HIGH
75.	HIGH	HIGH	LOW	HIGH	VERY HIGH
76.	HIGH	HIGH	MEDIUM	LOW	LOW
77.	HIGH	HIGH	MEDIUM	MEDIUM	HIGH
78.	HIGH	HIGH	MEDIUM	HIGH	VERY HIGH
79.	HIGH	HIGH	HIGH	LOW	VERY LOW
80.	HIGH	HIGH	HIGH	MEDIUM	HIGH
81.	HIGH	HIGH	HIGH	HIGH	HIGH



(a) (b)

(b) (d)

(a) represent graph for three antecedents,

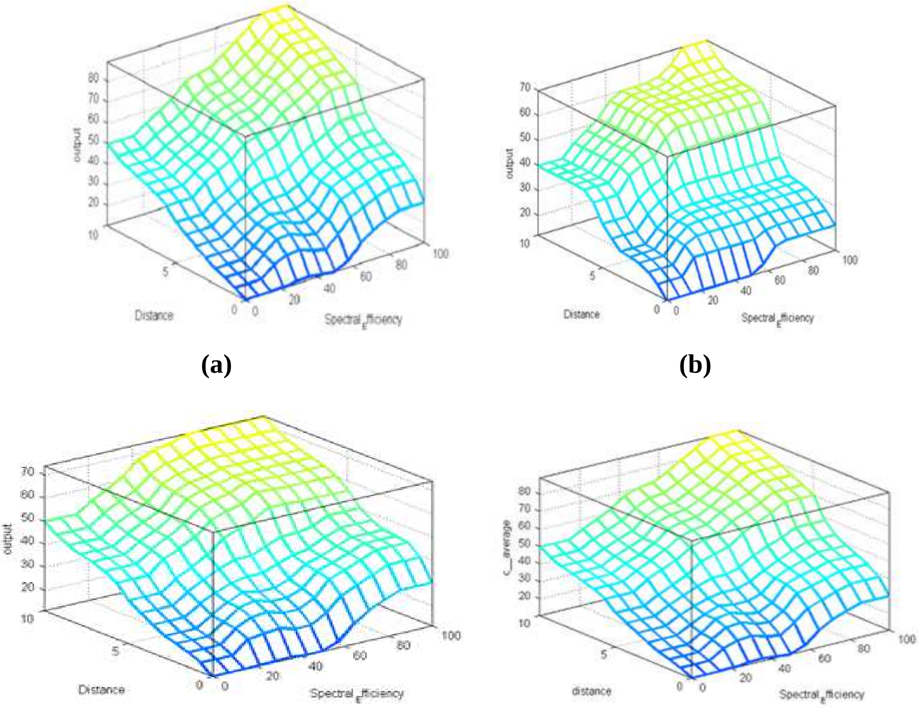
(b) represents case of four antecedents when signal strength is high,

(c) represents medium signal strength and

(d) represents low signal strength

Figure 5: Observed 2-D Plots in Which

Opportunity to access spectrum calculated by (5) is calculated as low for low signal strength, and for moderate signal strength it is moderate and for high signal strength it is high, that means user with high Signal Strength is preferred. But other parameter also contributes major issues as distance, opportunity to access spectrum increases as distance increases, and when efficiency is high. Mobility plays crucial role such that as it increases that is the number of hand over increases priority for access the spectrum opportunistically decreases. Above all things can easily observed from the surface plot shown in Figure 4(a), 4(b), 4(c), and 4(d). From Figure 3, we clearly see that, at the same spectrum utilization efficiency and mobility degree, secondary users further from the primary user with high signal strength have higher chance to access the spectrum. We have also compared our scheme with the scheme of opportunistic spectrum access (case of three antecedents with when signal strength is not considered) [21].



(a) **(b)**

(c) **(d)**

(a) surface plot for three antecedents

(b) represents case of four antecedent when signal strength is high,

(c) represents medium signal strength and

(d) represents low signal strength

Figure 6: Decision Surface of Combine Three Descriptor, Where

We observed that in three antecedent case priority to access the spectrum is given to that secondary user which has high spectral efficiency with farthest distance from primary user, similarly in our scheme we observed same results but we have introduced the fourth antecedent as signal strength in the range of low, moderate and high which modifies the results in terms of accuracy i.e. it can observed from Figure 4(a) and 4(b)that in case of low signal strength output or priority to access the spectrum calculated is low as compared the case of three antecedent, similarly for moderate signal strength it shows better result Figure 4(c), but when the case of high signal strength is considered we got the same result as for three antecedent. This shows that accuracy to give the priority to secondary users has been increased by introducing the signal strength as fourth parameter. Reliability of scheme is also increased as we scaled the accuracy in terms of fourth parameter introduced

VI. CONCLUSIONS

This paper proposes a scheme to use the underutilized spectrum of the primary users by secondary user opportunistically providing an efficient way to extract the available spectrum resource to its maximum, thus allowing the next generation radio network user to benefit from the available spectrum. The overall capacity of cognitive radio networks can be maximized with minimized interference. This scheme is a solution to the present scenario of overcrowded frequency spectrum of cognitive radio by controlling the opportunistic access of spectrum by secondary user using fuzzy logic concept. A fuzzy logic system (FLS) is used in this model to choose a secondary user having maximum possibility of spectrum access. The user is selected on the basis of its spectrum utilization efficiency, its mobility, its distance to the primary user and its signal strength. The above four parameters of all the secondary users are sensed and analyzed by the FLS based on the linguistic knowledge of these parameters. The user with highest possibility is then selected without causing any interference to the existing primary users and other secondary users. This scheme when compared with the scheme proposed for three parameters approach [21has an advantage of increased accuracy. Additionally, the modifications of the membership functions of input parameters in accordance to the requirements of the primary user network and the spectrum policies also provide flexibility for use in future cognitive radio networks. The further challenges that can be posed to the future researchers is to use an adaptive fuzzy logic system rather than a fixed rule based fuzzy logic system which will lead to more accuracy and flexibility and less degradation of quality of service (QoS).

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