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Decision Making in Spectrum Allocation in Cognitive Radio using Fuzzy Logic

P Gowthamarayathirumal
Research Scholar
Department of Computer Science
Periyar University
Salem, India
thirumalanbu.p@gmail.com

C Chandrasekar
Associate Professor
Department of Computer Science
Periyar University
Salem, India.
ccsekar@gmail.com

***Abstract*-Cognitive radio is considered as a software-defined platform that evolves a fully reconfigurable wireless transceiver which automatically adapts its communication parameters to network and user demands. By analyzing the radio environment as well as the primary and secondary user's environment and have to make a decision for which secondary user can be the best secondary user to access the spectrum from the primary user. Fuzzy logic approach is taken for indicating the environments for accessing the available spectrum by the secondary users. By using this fuzzy logic, possibility for every secondary user can be computed and the available spectrum accessing decision will be based on this possibility. So that, the secondary user who is having the highest possibility among all the secondary users will be considered and permitted to access the primary users spectrum. Thus, it will make more utilization of the available spectrum of the primary users without causing interference.**

Keywords - cognitive radio, linguistic variables, membership functions, SIR.

I. Introduction

The traditional spectrum allocation approaches like Static allocation of spectrum has several disadvantages because of being time and space invariant. In static spectrum allocation, parts of the radio spectrum have been statically allocated for various wireless networking services for the military, government, commercial, private and public safety systems [1]. In order to overcome these problems, there is a need for flexible communications in the network. A new approach named Cognitive Radio (CR) has been introduced in a report by Professor Cave. It was published in 2002 detailing the possibility of selling spectrum depended upon the bandwidth required. This CR technology would lend itself to this approach of spectrum management as it would be able to utilize areas that were temporarily free and thereby maximize the use of particular areas [2]. In fact the term Cognitive Radio was coined by Joseph Mitola while he was writing his doctoral thesis on the topic in 2002.

The primary network or licensed network is referred to as an existing network where the primary users have a license to operate in a certain spectrum band. If primary networks have an infrastructure, primary user activities are controlled through primary base stations. Due to their priority in spectrum access, the operations of primary users should not be affected by the secondary user or unlicensed users. The CR network (also called the dynamic spectrum access network, secondary network, or unlicensed network) does not have a license to operate in a desired band. Hence, additional functionality is required for CR users to share the licensed spectrum band. CR networks also can be equipped with CR base stations that provide single-hop connection to CR users. Finally, CR networks may include spectrum brokers that play a role in distributing the spectrum resources among different CR networks.

In order to access the band from the primary network, the CR radio will need to determine the occupancy of the available spectrum and then decide the best power level, mode of transmission, dynamic frequency selection and other necessary characteristics. Additionally the radio will need to be able to judge the level of interference it may cause to other users. This is an equally important requirement for the radio communications system if it is to operate effectively and be allowed access to bands that might otherwise be barred[3]. The CR must leave the primary network if it causes any interference or any degrades to the primary users or the need of spectrum for the primary users. So that the CR must be able to sense the radio environment to detect the unused Spectrum, capture the best available spectrum, exchanges the frequencies to the secondary users and to provide a fair spectrum scheduling method among the users[9].There are several challenges in the CR environment. One of the main

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challenges is sharing the spectrum in the CR. The main objective of this research is to detect the best secondary user from the CR environment to share the spectrum.

There are several attributes used to determine the best secondary users. From these attributes, Spectrum utilization, mobility and the distance of the secondary users are taken for selecting the best secondary user. Because of these three attributes are performing more vital role for selecting the best secondary users. In this approach, Fuzzy logic system is considered to detect secondary user who is having the effective spectrum access. By using this fuzzy concept, the attributes are taken as the antecedents in the fuzzy model. The values of each antecedent are computed by using Network Simulator 2. These values are fuzzified by using triangular and trapezoidal membership functions. By using these three antecedents, the possibility of each secondary user will be computed. In this work, all those three antecedents are considered as equal. So there is no priority is given to any antecedents. In this work Centre of Gravity method has taken to find the best secondary user.

II. THE MAIN FUNCTIONS OF COGNITIVE RADIOS

A. *Spectrum Sensing*

CR must be able to detect the unused frequency from the primary user and sharing it without harmful interference with secondary users, it is an important requirement of the CR network to sense spectrum holes, detecting the primary users is the most efficient way to detect the spectrum holes. There are a number of attributes that must be incorporated into any CR spectrum sensing scheme. These ensure that the spectrum sensing is undertaken to meet the requirements for the particular applications. The methodology and attributes assigned to the spectrum sensing ensure that the CR system is able to avoid interference to other users while maintaining its own performance.

B. *Spectrum Management*

It is used to capturing the best available spectrum to meet user communication requirements. CRs should decide on the best spectrum band to meet the Quality of service (QoS) requirements over all available spectrum bands.

C. *Spectrum analysis*

In this process, each spectrum hole should be characterized not only the time –varying radio environment and also the primary user activity.

D. *Spectrum decision*

When all the analysis of the spectrum band is done, appropriate spectrum band should be selected for the current transmission considering the QoS requirements and the spectrum characteristics. According to user requirement the data rate and bandwidth are determined. Then according to the decision rule the appropriate spectrum band is chosen.

E. *Spectrum Mobility*

CR users are regarded as visitors to the spectrum. Hence, if the specific portion of the spectrum in use is required by a primary user, the communication must be continued in another vacant portion of the spectrum. Spectrum mobility is defined as the process when a CR user exchanges its frequency of operation. CR networks target to use the spectrum in a dynamic manner by allowing the radio terminals to operate in the best available frequency band, maintaining seamless communication requirements during the transition to better spectrum.

F. *Spectrum Sharing*

Spectrum Sharing providing the fair spectrum scheduling method, one of the major challenges in open spectrum usage is the spectrum sharing. It can be regarded to be similar to the generic media access control MAC problems in existing systems. Because there may be multiple CR users trying to access the spectrum, CR network access should be coordinated to prevent multiple users colliding in overlapping portions of the spectrum.

III. FUZZY LOGIC SYSTEM

A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set into a scalar output data. FLS can able to simultaneously handle numerical data and linguistic knowledge[4].

The components and the general architecture of a FLS is shown in Figure 1.

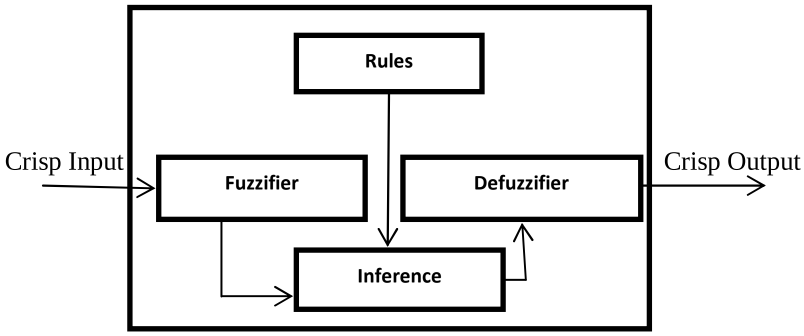

Figure 1: A Fuzzy Logic System

A. Fuzzifier

It is used for the process of making a crisp quantity into fuzzy. In the real world, hardware such as a digital voltmeter generates crisp data, but these data are subject to experimental error. Establishes the fact base of the fuzzy system, it identifies the input and output of the system, defines appropriate IF THEN rules, uses raw data to derive a membership function.

B. Fuzzy Rules

In a FLS, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion. Sample fuzzy rules for finding the best Secondary User in CR is as follows.

Example:

If (Antecedent1 is Low) AND (Antecedent2 is Low) AND (Antecedent3 is Low) THEN the consequence is Low.

C. Defuzzifier

It is used to convert the fuzzy value obtained from composition into a “crisp” value. This process is often complex since the fuzzy set might not translate directly into a crisp value. Defuzzification is necessary, since controllers of physical systems require discrete signals. It Convert the fuzzy output of the inference engine to crisp using membership functions analogous to the ones used by the fuzzifier.

D. Inference Engine

Using If-Then type fuzzy rules converts the fuzzy input to the fuzzy output. Fuzzy Inference Engine evaluates all rules and determines their truth values. It combines all fuzzy conclusions obtained by inference into a single conclusion. Since different fuzzy rules might have different conclusions so that all rules have to be considered. Each inference suggests a different action. A simple MAX-MIN method of selection is used where the maximum fuzzy value of the inferences is used as the final conclusion.

IV. RELATED WORK

In the existing approach using the rule based fuzzy logic system is used to control the opportunistic spectrum access for secondary users in CR networks, the secondary user was selected based on various descriptors, like number of interferences, velocity, Spectrum utilization efficiency, degree of mobility, path loss between transmitter & receiver, and hold time of licensed band. The linguistic knowledge of spectrum access is based on the experiences from a group of network exports, so that an acceptable decision can be obtained. As a result, represent the best secondary user.

The Authors in [9] discussed in their paper to enhance the spectrum aware communication by the work in order to fulfill the present status of the spectrum utilization and avoiding the spectrum scarcity. Spectrum allocation method by opportunistic spectrum access scenario using cognitive radio was analyzed and simulated using NS2 Simulator in order to validate in their approach.

In the existing approach, the experts chose the linguistic labels with triangular membership functions for the antecedents which are spectrum utilization, mobility and distance. Even though it produces good result but trapezoidal membership provides much better results because fixing a particular point as low, medium and high is not efficient in these types of conditional attributes. So, we are fixing a particular range of values as low, medium and high in this paper.

In this approach three antecedents such as spectrum utilization of the secondary user, degree of mobility of the secondary user and the distance between the primary and the secondary user. The linguistic variables low, moderate and high are taken to specify the utilization and the mobility of the secondary user. Near, medium and far are the linguistic variables used to represent the mobility of the secondary user. The possibility of all the available secondary users are categorized as very low, low, medium, high and very high by using the combination of triangular and trapezoidal membership functions.

V. FINDING POSSIBILITIES OF SECONDARY USERS

A. *Fuzzy logic for opportunistic spectrum access*

Fuzzy logic approach has chosen for selecting the best primary user in the CR. In this approach, the best secondary user can be defined as the user who is having the high spectrum utilization with low mobility and farthest distance from the primary user [5]. Although the interference and the energy used by the secondary user is also very important role for selecting the best primary user in the CR environment, but they can defined by the antecedents distance and mobility. The antecedents are

Antecedent 1: Spectrum Utilization Efficiency

Antecedent 2: Degree of Mobility

Antecedent 3: Distance between the Primary and Secondary User

B. *Spectrum Utilization*

The primary user may use minimum or maximum spectrum from their network depending on various factors. The primary network can have some frequency range for emergency purpose. The rest of the frequency will be considered for the cognitive users. The amount of frequency will be utilized from the cognitive spectrum by the secondary user has the vital role in the best secondary user selection.

We apply different available spectrum in order to find out the spectrum efficiency which is the main purpose of the opportunistic spectrum access strategy. Hence, we calculate the spectrum efficiency ηs as the ratio of average busy spectrum over total available spectrum owned by secondary users, i.e.,

$$\eta_s = \frac{\eta_{\text{busy spectrum}}}{\eta_{\text{available spectrum}}} \tag{1}$$

Where $\eta_{\text{busy spectrum}}$ is the number of busy spectrum used at time t for secondary user and $\eta_{\text{available spectrum}}$ is the total available spectrum respectively.

C. *Degree of Mobility*

Mobility is one of the important factors for selecting the best secondary user. Because, the spectrum hole in the primary network will not be in the sequential manner. The various range of spectrum will be allocated to the secondary user according to the usage of spectrum by the primary user [10]. If the primary user needs the spectrum then the secondary user has to vacate some of the spectrum holes which they used.

The movement of the secondary user leads to a shift of the received frequency, called the Doppler shift. When the secondary user is moving at a velocity v m/s, it causes the Doppler Effect.

The Doppler Effect leads to a shift of the received frequency f_D by the amount v, so that the received frequency is given by:

$$f_D = \frac{v \cos\theta}{c} f_c \qquad = f_{c\_v} \tag{2}$$

where f_D is the Doppler shift, θ denotes the angle between the velocity vector v of the MS and the direction of the wave at the location of the MS, c is the wave velocity, and f is carrier frequency.

D. Distance

The main problem of CR is to access the primary user's spectrum without producing any interference to the primary users. If the distance between the primary and the secondary user is high then it will produce interference. so that the secondary user who is farthest distance from the primary user will be considered for accessing the spectrum[6].

The Distance between the primary user and the secondary users were calculated using the formula

$$D_i = \frac{d_i}{max_{i=1}^{20}\{d_i\}} \quad (3)$$

$$d_i = \sqrt{(x_i - x_p)^2 + (y_i - y_p)^2} \quad (4)$$

Where x_p and y_p are the distances of the primary users and x_i and y_i are the distances of the secondary users from the primary user.

E. Knowledge processing using opportunistic spectrum access

The Proposed algorithm is used for finding the possibility based on three antecedents and also finding the spectrum utilization efficiency as shown in the Table 1.

Table 1: Algorithm for accessing opportunistic spectrum access

Step1: Initialization phase: Input from information table Spectrum Access ={*l*, i, X,C}
where $l=\{l_1,l_2,\ldots,l_n\}$, $i=\{a_1,a_2,\ldots,a_m\}$, $X=\{x_1,x_2,\ldots,x_n\}$, $C=\{c_1,c_2,\ldots,c_n\}$

Step2: Finding out the spectrum utilization efficiency η_s

$$\eta_s = n_{bs} / n_{as} \quad (5)$$

n_{bs} - the number of busy spectrum used at time t for secondary user.
n_{as} - the total available spectrum.

Step3: Finding out the distance of Primary user to the secondary users

$$D_i = \frac{d_i}{max_{i=1}^{20}\{d_i\}} \quad \text{where} \quad d_i = \sqrt{(x_i - x_p)^2 + (y_i - y_p)^2} \quad (6)$$

here i={1,2,3,4,5} and p={1,2,3,…,20}. x_p and y_p are the distances of the primary users.
x_i and y_i are the distances of the secondary users from the primary user.

Step4: Finding out the degree of mobility of the secondary users.

$$f_D = \frac{v \cos\theta}{c} f_c \quad (7)$$

Step5: Normalize the input data by using Max-Min method.

$$\text{Input} = \frac{Xi - Min(X)}{Max(X) - Min(X)} \quad (8)$$

Step6: Fuzzification phase: Fuzzifying every antecedents by using different membership functions [8].

$$X = \sum_{i=1}^{n}\sum_{j=1}^{m}\{((x_i, a_{ij})c_i),((x_{i+1}, a_{i+1j+1})c_{i+1}),\ldots,((x_n, a_{nm})c_n)\} \quad (9)$$

Where n=5 and m=27.

Step 7: Rule generations:

IF a_1 is F_l^1 and a_2 is F_l^2 and a_p is F_l^p , THEN *c* is B_i .

Where, *l* is the linguistic variables, a_1, a_2, a_p are antecedents.

B_i is the linguistic variable for consequence

Step8: Finding the c^l_{avg} for every antecedents

$$c^{l}_{avg} = \frac{\sum_{i=1}^{5} w_i^l c^i}{\sum_{i=1}^{5} w_i^l} \quad (10)$$

where *l* is the linguistic variables, w_i^l is the weight for every linguistic variable *i* for Consequence rule *l* and C^i centroid for every linguistic variable.

$$C^i = \frac{\sum_{i=1}^{27} x_i \mu_j^{\,l}(x_i)}{\sum_{i=1}^{27} \mu_j^{\,l}(x_i)} \quad (11)$$

Where $\mu_j^{\,l}(x_i)$ is the membership value for every object for each antecedents.

Step9: Defuzzification phase: Every input (x1, x2, x3) and the output y(x1, x2, x3) of designed FLS computed as

$$y(x_1, x_2, x_3) = \frac{\sum_{i=1}^{27} \mu_{F_1^l(x_1)} \mu_{F_2^l(x_2)} \mu_{F_3^l(x_3)} c^l_{avg}}{\sum_{i=1}^{27} \mu_{F_1^l(x_1)} \mu_{F_2^l(x_2)} \mu_{F_3^l(x_3)}}, \quad (12)$$

where i={1,2,...27}

Step10: Selecting the Secondary users by finding out the highest possibility based on the three antecedents.

Step11: Opportunistic spectrum access is carried out by the best Secondary user.

F. *Data set*

The values for spectrum utilization, mobility and distance are computed in network simulator. In this, 5 secondary users are represented here for finding the best secondary user. The values are represented in the below Table 2.

Table 2: Simulation values for each antecedents of SU.

Secondary Users	Utilization	Mobility	Distance
SU1	83.0274	0.006667	8.41
SU2	70.8922	0.011045	8.53
SU3	70.7237	0.005223	12.88
SU4	68.2424	0.007488	9.62
SU5	67.5845	0.012421	6.02

G. *Data Normalization*

Due to the inconsistency of the data, the data set has normalized by using Max-Min normalization technique.

$$Normalized\ data = \frac{x - Min(x)}{Max(x) - Min(x)} \quad (13)$$

Let x be any value from the data set, Min represents the minimum value of the data set and Max represents the maximum value of the data set. The normalized data set is represented in the following table.

Table 3: Normalized Data

Secondary Users	Utilization	Mobility	Distance
SU1	0.790498	0.27967	0.610028
SU2	0.446566	0.827742	0.620750
SU3	0.44179	0.098898	1
SU4	0.371466	0.382449	0.71578
SU5	0.35282	1	0.401918
SU6	0	0.382449	0.665301

H. Fuzzification

In this phase each and every crisp input will be converted to fuzzy values by using the triangular and the trapezoidal membership function. The membership of the value is in between the closed interval 0 to 1. The values can be represented by using the following linguistic variables.

Fuzzification can be done by using the following ranges.

- **Antecedents:**
  Low & Near (trapezoidal) = [-0.5 -0.1 0.1 0.5]
  Moderate & Medium (triangular) = [0.1 0.5 0.9]
  High & Far (trapezoidal) = [0.5 0.9 1.1 1.5]

- **Consequence:**
  Very Low (trapezoidal) = [- 0.1 0 0.1 0.3]
  Low (triangular) = [0.1 0.3 0.5]
  Medium (triangular) = [0.3 0.5 0.7]
  High (triangular) = [0.5 0.7 0.9]
  Very High (trapezoidal) = [0.7 0.9 1.1 1.3]

I. Membership Functions

In this approach 3 levels of Linguistic variables are used to represent the spectrum utilization, distance and degree of mobility. The linguistic variable low, moderate and high are used to represent the spectrum utilization and the degree of mobility. The linguistic variable near, moderate and far are used to represent the distance[8].

Triangular membership value is computed by using

$$\mu_A(x) = \begin{cases} 0 & if \ x \le a \\ \dfrac{x-a}{b-a} & if \ a \le x \le b \\ \dfrac{c-x}{c-b} & if \ b \le x \le c \\ 0 & if \ x \ge c \end{cases} \qquad (14)$$

Here, a is the lower limit, b is the peak point and c is the upper limit of triangle.

Trapezoidal membership value is computed by using

$$f(x, a, b, c, d) = \begin{cases} 0 & \text{if} \quad x < a \ \& \ x > d \\ (x - a) / (b - a) & \text{if} \quad a <= x <= b \\ 1 & \text{if} \quad b <= x <= c \\ (d - x) / (d - c) & \text{if} \quad c <= x <= d \end{cases} \qquad (15)$$

Here, a & b are lower and upper limits, and c & d are the core of the trapezoid.

Antecedents:

The below represented Figure 2 shows the ranges and the membership values of the spectrum of the secondary user.

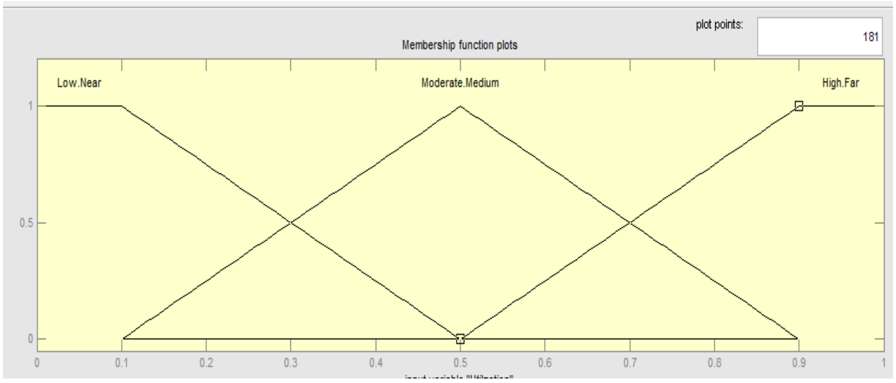

Figure 2: Membership Functions of Antecedents

Consequence:

The consequence, i.e., 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. Trapezoidal membership function is used to represent very low and very high. Triangular is used to represent low, medium and high.

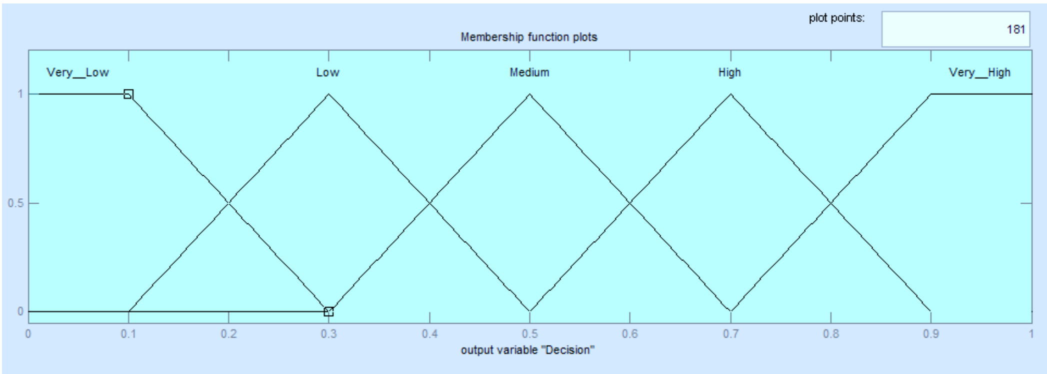

Figure 3: Membership Function for the consequence

Fuzzy Rules

In a FLS, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion [7]. Sample fuzzy rules for finding the best Secondary User in CR is as follows.

1. If (utilization is Low) AND (Mobility is Low) AND (distance is Near) THEN the decision is Low.
2. If (utilization is Low) AND (Mobility is Low) AND (distance is Moderate) THEN the decision is Medium.
3. If (utilization is Low) AND (Mobility is Low) AND (distance is Far) THEN the decision is High.

We have 3 antecedents with 3 linguistic values and fuzzy subsets we need to setup $3^3 = 27$ rules for this FLS. The rules for taking decision is mentioned in the below Table 4.

Table 4: Fuzzy Rules

S. No.	Utilization	Mobility	Distance	Decision
1	Low	Low	Near	Very low
2	Low	Low	Moderate	Low
3	Low	Low	Far	Medium
4	Low	Moderate	Near	Very low
5	Low	Moderate	Moderate	Low
6	Low	Moderate	Far	Medium
7	Low	High	Near	Very low

8	Low	High	Moderate	Very low
9	Low	High	Far	Low
10	Moderate	Low	Near	Very low
11	Moderate	Low	Moderate	High
12	Moderate	Low	Far	Very high
13	Moderate	Moderate	Near	Very low
14	Moderate	Moderate	Moderate	Medium
15	Moderate	Moderate	Far	High
16	Moderate	High	Near	Very low
17	Moderate	High	Moderate	Low
18	Moderate	High	Far	Medium
19	High	Low	Near	Very low
20	High	Low	Moderate	High
21	High	Low	Far	Very high
22	High	Moderate	Near	Very low
23	High	Moderate	Moderate	Medium
24	High	Moderate	Far	Very high
25	High	High	Near	Very low
26	High	High	Moderate	Medium
27	High	High	Far	High

VI. SIMULATION RESULTS AND DISCUSSIONS

In this section, we present simulation results on the performance of our proposed work based on Fuzzy logic System. In the proposed work, we are choosing the available channel with the highest possibility.

Table 5: Simulation Parameters

Parameters	**Values**
Energy model	Energy Model
Channel	Wireless Channel
Propagation Model	TwoRayGround Model
Initial energy	100 J
Number of nodes	21
X Value	1000 m
Y value	1000 m
Number of Base station	2
Number of Primary user	1
Number of Secondary user	20
Pause time	5.00s
Maximum Speed	4.00
Queue length	100
rxPower	0.3
txPower	0.6

A. *Possibility*

The Possibility value for each rule is calculated by using Centroid of Area defuzzification method.

Table 6: Possibility of secondary users

Secondary Users	Utilization	Mobility	Distance	Possibility (%)
SU1	83.0274	0.006667	8.41	65.0
SU2	70.8922	0.011045	8.53	40.1
SU3	70.7237	0.005223	12.88	80.3
SU4	68.2424	0.007488	9.62	57.5
SU5	67.5845	0.012421	6.02	24.6
SU6	55.1357	0.007488	9.041	38.6

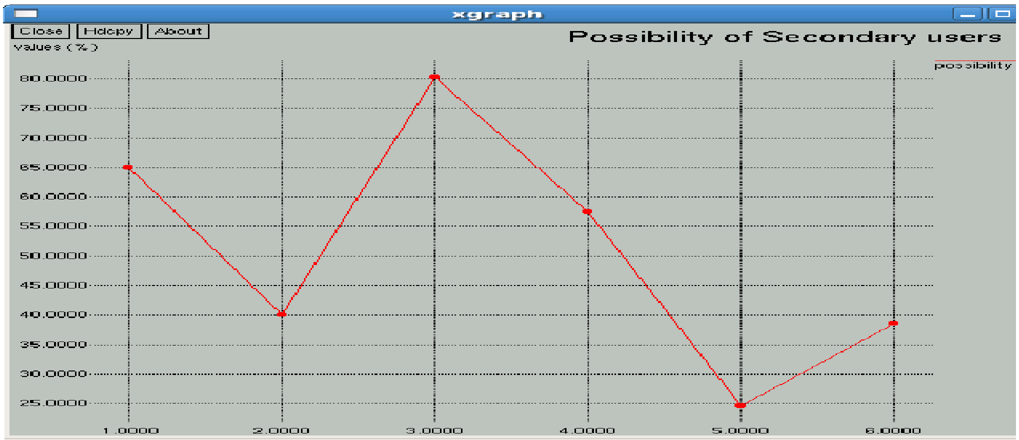

Figure 4: Xgraph for possibility of secondary user

Although other SUs have very effective in a particular antecedent, the spectrum allocation will be based on the three antecedents by using its possibility. In spite of the highest Possibility, the SU3 will be considered as the best secondary user. So that, the SU3 will be permitted to access the primary users used spectrum.

B. Signal to Interference Ratio

The Signal to Interference Ratio (S/I or SIR) is the quotient between the average received modulated carrier power (S) and the average received Interference (I) power. i.e. Cross talk from other transmitters than the useful signal.

$$\frac{S}{I} = \frac{(D/R)^n}{i_o} \tag{16}$$

Here,

S = Received Carrier Power, I = Received Interference Power

D = Distance of the user, R = Cell Radius, n = Path Loss Exponent, io = Number of Neighboring cell

To convert S/I (%) to Decibels

$$S/I = 10 \log (S/I) \tag{17}$$

In the simulation environment, Radius of dense urban R = 3, Path loss exponent n = 3 and the Neighboring cell for the hexagonal coverage area i_o = 6.

Table 7: Signal to Interference Ration of secondary users

Secondary Users	Utilization	Mobility	Distance	SIR (dB)
SU1	83.0274	0.006667	8.41	18.74935
SU2	70.8922	0.011045	8.53	19.37787
SU3	70.7237	0.005223	12.88	37.21332
SU4	68.2424	0.007488	9.62	24.58261
SU5	67.5845	0.012421	6.02	4.294405
SU6	55.1357	0.007488	9.041	21.89597

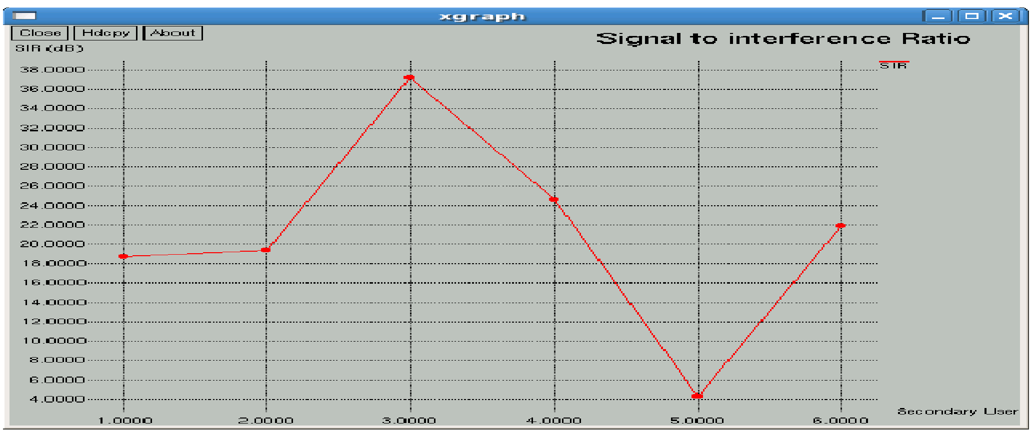

Figure 5: Xgraph for Signal to Interference Ratio

For the above environment, the minimum acceptable level of SIR is 15 dB. By this above graph SU 5 does not have the minimum signal to interference ratio. If we allocate spectrum to SU 5 will produce severe interference to the primary users.

VII. CONCLUSION

This work allows the secondary user to access the unused frequencies from the primary network without interference to the primary user. So that maximum level of spectrum will be utilized by the users. It will create the next generation mobile network users to benefit from available radio spectrum, leading to the improvement of overall spectrum utilization and maximizing overall PU and SU networks capacity. Here, we proposed an approach using a Fuzzy Logic System to detect the best secondary user who can capable of effective spectrum access via CR. The secondary users are selected on the basis of spectrum utilization, degree of mobility and distance from secondary users to the primary user. By using the above antecedents, the possibility of spectrum access is computed for each and every secondary user in the CR environment. By allocating the spectrum to the secondary user who is having the highest possibility can be able to access the frequency from the primary network without producing interference to the primary user and also can access the spectrum with high efficiency. This work minimized the interference and maximizes the spectrum usage. So that it has better and efficient spectrum utilization.

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