Fuzzy Logic System for Opportunistic Spectrum Access using Cognitive Radio

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Abstract

Opportunistic spectrum access approach is enabled by cognitive radios which are able to sense the unused spectrum and adapt their operating characteristics to the real-time environment. However, a naive spectrum access for secondary users can make spectrum utilization inefficient and increase interference to adjacent users. In this paper, we propose a novel approach using Fuzzy Logic System (FLS) to control the spectrum access and spectrum for secondary user is selected by possibility of the spectrum access instead of considering the antecedents.

Keywords: *Antecedent, FLS, Interference, Spectrum access, spectrum utilization.*

1. Introduction

In recent studies, the spectrum allocated by the traditional approach shows that the spectrum allocated to the primary user is under-utilized and the demand for accessing the limited spectrum is growing increasingly. Spectrum is no longer sufficiently available, because it has been assigned to primary users that own the privileges to their assigned spectrum.

The concept of opportunistic spectrum access is used in order to efficiently utilize the spectrum which is under-utilized. The opportunistic spectrum access improves the spectrum utilization by cognitive radio adopting the secondary user to use the unused spectrum of the primary user. This opportunistic spectrum access, avoids the spectrum scarcity.

The idea of cognitive radio was first presented officially in an article by Joseph Mitola III and Gerald Q. Maguire, Jr in 1999. Regulatory bodies in various countries found that most of the radio frequency spectrum was inefficiently utilized. For example, cellular network bands are overloaded in most parts of the world, but amateur radio and paging frequencies are not. This can be eradicated using the dynamic spectrum access.

The key enabling technology of dynamic spectrum access techniques is cognitive radio (CR) technology, which provides the capability to share the wireless channel with licensed users in an opportunistic manner. From this definition, two main characteristics of the cognitive radio can be defined as follows:

- Cognitive capability: It refers to the ability of the radio technology to capture or sense the information from its radio environment. Through this capability, the portions of the spectrum that are unused at a specific time or location can be identified. Consequently, the best spectrum and appropriate operating parameters can be selected.
- Reconfigurability: The cognitive capability provides spectrum awareness whereas reconfigurability enables the radio to be dynamically programmed according to the radio environment.

More specifically, the cognitive radio technology will enable the users to (1) determine which portions of the spectrum is available and detect the presence of licensed users when a user operates in a licensed band (spectrum sensing), (2) select the best available channel (spectrum management), (3) coordinate access to this channel with other users (spectrum sharing), and (4) vacate the channel when a licensed user is detected (spectrum mobility).

The paper is organized as follows; Section 2 and 3 provide the related work and fuzzy logic system for its implementation. In section 4 and 5, opportunistic spectrum access by Fuzzy logic system to improve the spectrum efficiency and performance analysis. Finally, conclusions are presented in Section 6.

2. Related Work

In the research literature on the opportunistic spectrum access, different methods are applied using fuzzy logic to access spectrum efficiently. In [7], a novel approach using Fuzzy logic system provides the possibility of accessing spectrum band for secondary users and the user with the greatest possibility has to be assigned the available spectrum band. For enhancing the performance of Cognitive radio fuzzy logic based scheme is developed by Anilesh Dey et al., [8], where efficient spectrum utilization depends upon the link loss, hold time and interference temperature. With fuzzy controller, Cognitive radio opportunistically adjust its transmit power in response to the changes of the interference level to the primary user is discussed in [9].

A Fuzzy logic based algorithm [10] is used to reduce the spectrum handoff and improves the probability of PU's occupancy at a certain channel. In [11], Fuzzy rules are used to optimize the bandwidth allocation based on three antecedents as: arrival rate of both licensed and unlicensed users and the availability of unoccupied number of channels within the system. A decentralized method has been developed using fuzzy based techniques for both channel estimation and channel selection in [12].

The efficient decision making in the cognitive radio by fuzzy logic is also discussed by Matinmikko et al [13], which presented an overview of application of fuzzy logic to telecommunications. Our work is different from the above said works available on Cognitive radio based on fuzzy logic system.

This paper presents a novel approach using Fuzzy logic system to utilize the available spectrum by the secondary users without interference with the primary user. The secondary users access the spectrum based on the highest possibility of the secondary users.

3. Fuzzy Logic

3.1 Fuzzy sets

Fuzzy sets theory is an excellent mathematical tool to handle the uncertainty arising due to vagueness. Fuzzy sets may be viewed as an extension and generalization of the basic concepts of crisp sets. An important property of fuzzy set is that it allows partial membership. Fuzzy set is the description of fuzzy events and conceptions. The fuzzy events means some events that there are no strict boundary and cannot be characterize easily by exact measurement. Fuzzy logic theory can model the vagueness of the real world.

A Fuzzy Logic System (FLS) is unique in that it is able to simultaneously handle numerical data and linguistic knowledge. It is a nonlinear mapping of an input data (feature) vector into a scalar output, i.e., it maps numbers into numbers. FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. FL's approach to control problems mimics how a person would make decisions, only much faster. Figure 1 shows the structure of a fuzzy logic system.

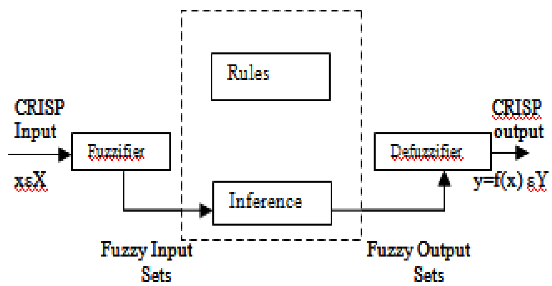

Fig. 1. The Structure of the Fuzzy Logic System

Since there is a need to "fuzzify" the fuzzy results we generate through a fuzzy system analysis i.e., we may eventually find a need to convert the fuzzy results to crisp results. Here, we may want to transform a fuzzy partition or pattern into a crisp partition or pattern; in control we may want to give a single-valued input instead of a fuzzy input command. The "dufuzzification" has the result of reducing a fuzzy set to a crisp single-valued quantity, or to a crisp set.

Generally, Fuzzy Logic and Fuzzy decision making is divided into three consecutive phases namely Fuzzification, Fuzzy reasoning and Dufuzzification [17].

1. Fuzzification: The input variables are fuzzified using predefined membership functions (MF). Unlike in binary logic where only 0 and 1 are accepted, also numbers between 0 and 1 are used in fuzzy logic. This is accomplished with MF to which the input variables are compared. The output of fuzzification is a set of fuzzy numbers.

2. Fuzzy reasoning: Fuzzy numbers are fed into the predefined rule base that presents the relations of the input and output variables with IF – THEN Clauses. The output of the fuzzy reasoning is a fuzzy variable that is composed of the THEN clauses.

3. Dufuzzification: The output of the fuzzy reasoning is changed into a non-fuzzy number that represents the actual output of the system.

3.2 Membership Functions

Consider a fuzzy logic system with a rule base of M rules, and let the lth rule be denoted by R_l. Let each rule have p antecedents and one consequent (as is well known, a rule with q consequents can be decomposed into rules, each having the same antecedents and one different consequent), i.e., it is of the general form

$$R_l : \text{IF } u_1 \text{ is } F_l^1 \text{ and } u_2 \text{ is } F_l^2 \text{ and} \ldots \text{and } u_p \text{ is } F_l^p, \text{ THEN } v \text{ is } G^l .$$

where $u_k, K = 1,....p$ and v are the input and output linguistic variables, respectively.

While applying a singleton fuzzification, when an input $X' = \{x'_1, x'_2, x'_3,...x'_p\}$ is applied, the degree of firing corresponding to the lth rule is given by

$$x^* = \frac{\sum_{i=1}^{n} x_i.\mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)} \quad (1)$$

Where * denotes a T-norm, n represents the number of elements, x_i 's are the elements and $\mu(x_i)$ is its membership function.

There are many kinds of dufuzzification methods, but we have chosen the centre of sets method for illustrative purpose. It computes a crisp output for the FLS by first computing the centroid, C_{G^l} of every consequent set G^l and, then computing weighted average of these centroids. The weight corresponding to the lth rule consequent centroid is the degree of firing associated with the lth rule, $T_{i=1}^{p} \mu_{F_1^l}(x'_1)$, so that

$$y_{cos}(x') = \frac{\sum_{l=1}^{M} C_{G^l} T_{i=1}^{p} \mu_{F_1^l}(x'_1)}{\sum_{l=1}^{M} T_{i=1}^{p} \mu_{F_1^l}(x'_1)} \quad (2)$$

where M is the number of rules in the FLS.

We use trapezoidal membership functions (MFs) to represent near, low, far, high, very low and very high, and triangle MFs to represent moderate, low, medium and high. MFs are shown in Fig. 2, 3, 4. Since we have 3 antecedents and fuzzy subsets, we need setup $3^3 = 27$ rules for this FLS.

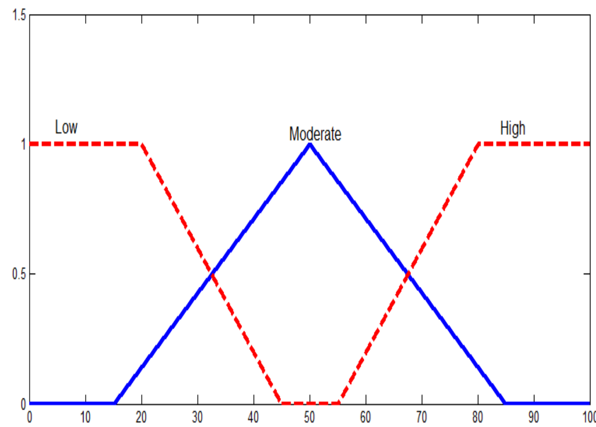

Fig. 2. Membership Function (MF) used to represent the antecedent1

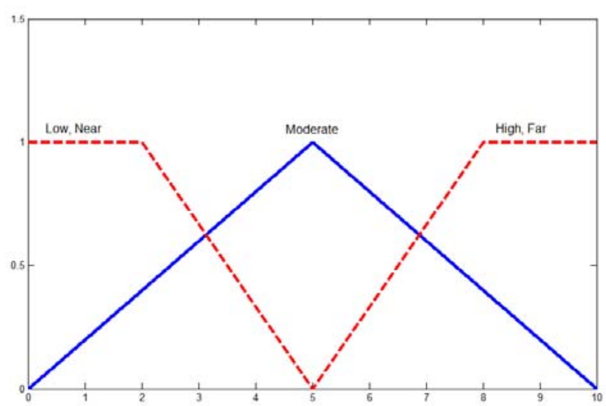

Fig. 3. Membership Function (MF) used to represent the antecedent2

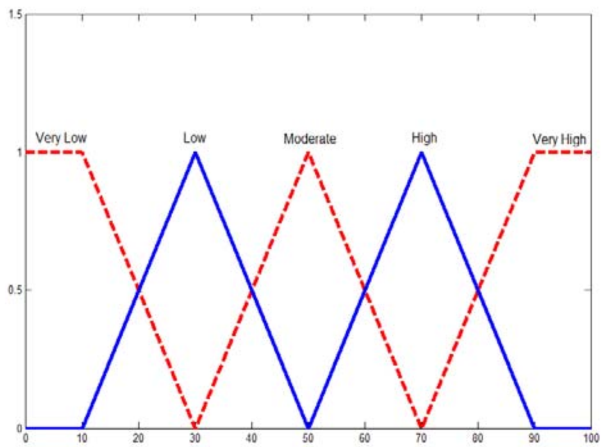

Fig. 4. Membership Function (MF) used to represent the antecedent3

Linguistic variables are used to represent the spectrum utilization efficiency; distance and degree of mobility are divided into three levels: low, moderate, and high. We use 3 levels to represent the distance, i.e., near, moderate.

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.

4. Fuzzy Logic for Opportunistic Spectrum Access

We design the fuzzy logic for opportunistic spectrum access using cognitive radio. In this paper, we are selecting the best suitable secondary users to access the available users without any interference with the primary users. This is collected based on the following three antecedents i.e., descriptors. They are

Ant 1 : Spectrum Utilization Efficiency
Ant 2 : Degree of Mobility
Ant 3 : Distance of Secondary user to the PU.

Fuzzy logic is used because it is a multi-valued logic and many input parameters can be considered to take the decision. Generally, the secondary user with the furthest distance to the primary user or the secondary user with maximum spectrum utilization efficiency can be chosen to access spectrum under the constraint that no interference is created for the primary user.

In our approach, we combine the three antecedents to allocate spectrum opportunistically inorder to find out the optimal solutions using the fuzzy logic system.

Mobility of the secondary user plays a vital role in the proposed work. Wireless systems also differ in the amount of mobility that they have to allow for the users. Spectrum Mobility is defined as the process when a cognitive radio user exchanges its frequency of operation. The movement of the secondary user leads to a shift of the received frequency, called the Doppler shift.

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

Since we chose a single consequent for each rule to form a rule base, we averaged the centroids of all the responses for each rule and used this average in place of the rule consequent centroid. Doing this leads to rules that have the following form:

$R^{'}$: If Degree of mobility (x_1) is F_l^1 ; and its distance between primary user and the secondary users (x_2) is F_l^2 ; and the spectrum utilization efficiency of the secondary user ($x3$) is F_l^3 , then the Possibility (y) choosing the available spectrum is c_{avg}^l , where l = 1,2,..27 and c_{avg}^l is defined as follows:

$$c_{avg}^{l} = \frac{\sum_{i=1}^{5} w_i^l c^i}{\sum_{i=1}^{5} w_i^l} \quad (3)$$

which w_i^l is the number of choosing linguistic label i for the consequence of rule l and c^i is the centroid of the i[th] consequence set (i: 1; 2; ...; 5; l: 1; 2; ...; 27). Table 2 provides c^i for each rule. For every input (x_1, x_2, x_3) , the output y(x_1, x_2, x_3) of the designed FLS is computed as

$$y(x_1, x_2, x_3) = \frac{\sum_{i=1}^{27} \mu_{F_1^l(x_1)} \mu_{F_2^l(x_2)} \mu_{F_3^l(x_3)} c_{avg}^l}{\sum_{i=1}^{27} \mu_{F_1^l(x_1)} \mu_{F_2^l(x_2)} \mu_{F_3^l(x_3)}} \quad (4)$$

which gives the possibility that a secondary user is selected to access the available spectrum.

In Figure 5, shows that the Spectrum user (SU4) having the highest possibility of accessing the spectrum than the other users. Even though the other secondary users have the furthest distance from primary user to the secondary users, highest spectrum utilization and highest mobility but we prefer SU4 to access the spectrum because it has the highest possibility i.e., 58.62.

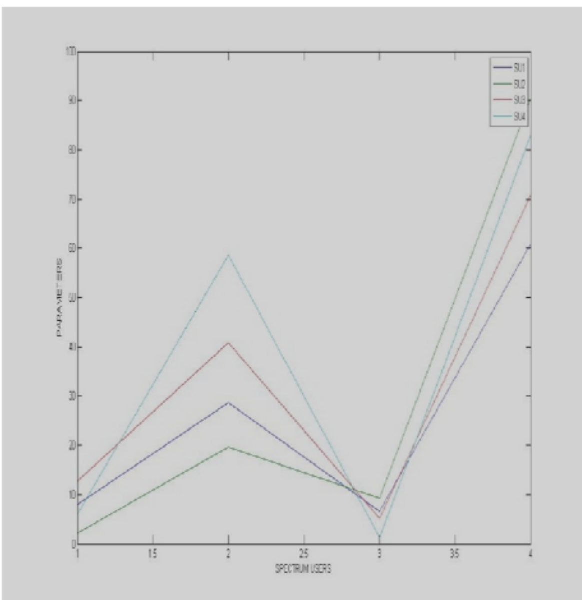

Fig. 5. Possibility of choosing spectrum for opportunistic spectrum access

Thus, the secondary user will select the spectrum for accessing based on the highest possibility rather than the highest spectrum utilization and the furthest distance from the primary user.

4. Performance Analysis

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 high possibility and high spectrum utilization efficiency.

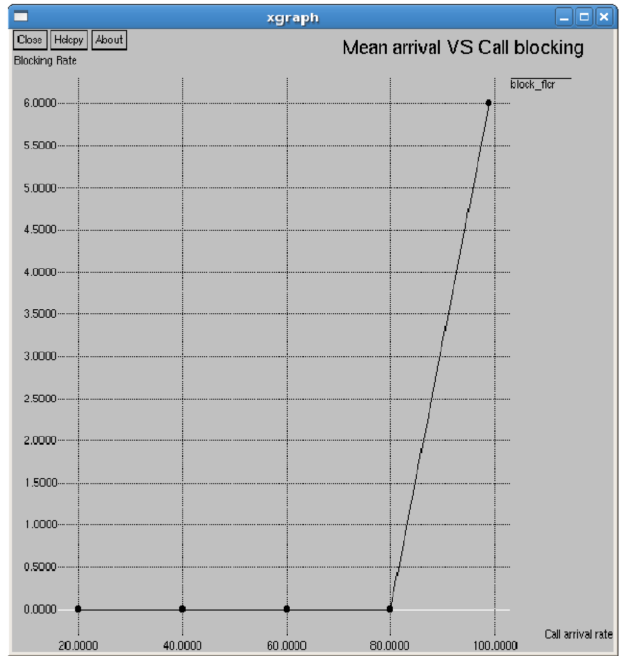

Fig. 6. Mean Arrival VS Call blocking rate

Figure 6 shows the call blocking of the service provider using the Fuzzy logic system. As the call arrival rate increases the blocking rate gets decreased. Traffic rate increases along with the call blocking rate.

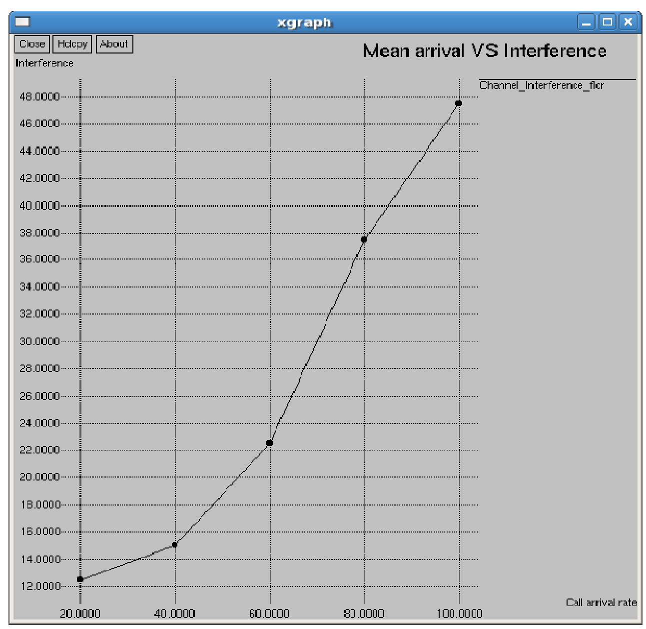

Fig. 7. Mean Arrival VS Interference using FLS

When interference increases spectrum utilization will decrease. The Figure 7 shows that there is a decrease in the interference which provides an increase spectrum utilization using FLS. This leads to efficient spectrum utilization.

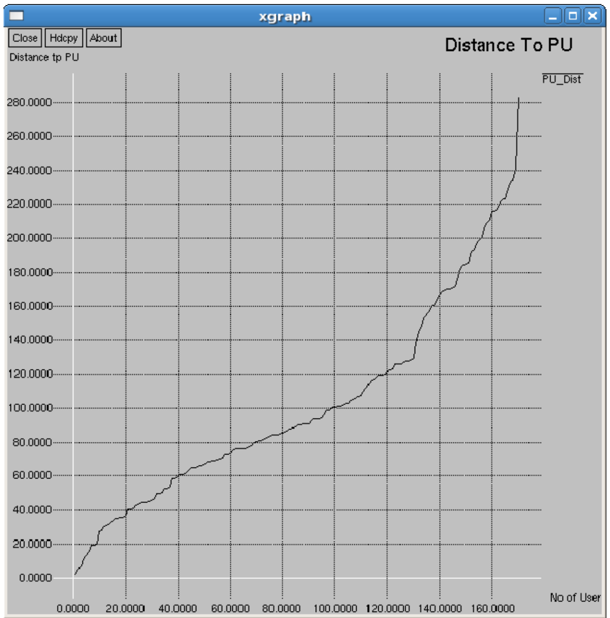

Fig. 8. Distance of Secondary Users to the Primary users using FLS

As illustrated in the Figure 8, the distance from primary user to the secondary users is shown. The distance between primary user and the secondary users helps us for calculating the possibility for accessing the spectrum opportunistically.

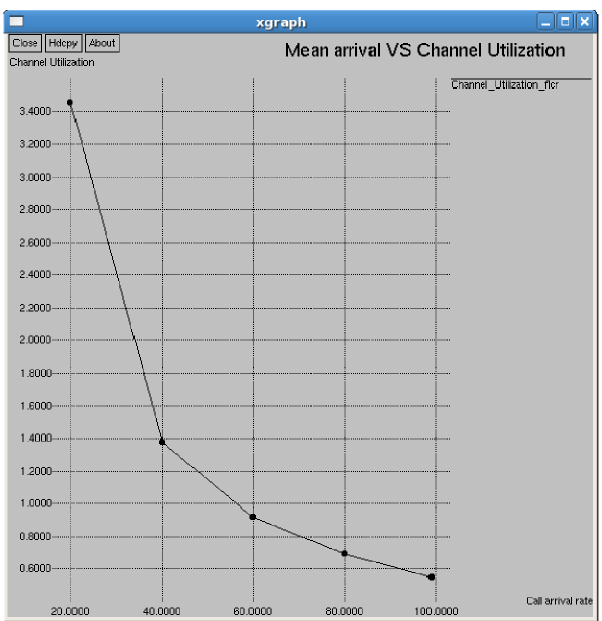

Fig. 9. Mean Arrival VS Channel Utilization using FLS

The Spectrum Efficiency (Channel Utilization) is defined as the ratio of average busy channels over total channels owned by service providers. The Figure 9 shows that there is an increase in channel utilization with decrease in the call arrival rate.

4. Conclusions

The proposed approach using a Fuzzy Logic System detects the effective spectrum access for secondary users via cognitive radio. The secondary users are selected on the basis of spectrum utilization, degree of mobility and distance from secondary users to the primary user. Our designed FLS is used to control the spectrum assignment and access procedures in order to prevent multiple users from colliding in overlapping spectrum portions. Therefore, the secondary user with the highest possibility is guaranteed to access the spectrum.

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