Spectrum selection Through Resource Management in Cognitive Environment

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***Abstract*—Spectrum is a scarce resource. The cognitive radio environments utilize the spectrum efficiently through the dynamic spectrum access approach. Game theory, genetic algorithms, neural network, marketing, and economic models became the catalysts to boost the dynamic spectrum access for efficient utilization of the spectrum. Combinations of these models may sometimes help better in the allocation of unused spectrum (spectrum holes) for cognitive users (secondary users). The paper introduced the electronic commerce model to identify a quality channel preferred by the secondary user. The rating of the spectrum (channel) was modeled with a combination of Sporas formula and fuzzy reputation model proposed by Carbo, Molina and Davila. The proposed model helps to select the quality channel to cognitive user. Further, the cooperative game theory was introduced to gain the better channel by the cognitive user. The channel selection also tested with automated collaborative filtering and case-based reason applications.**

Keywords-dynamic spectrum access; spectrum holes; cooperative games, fuzzy rating, cognitive user.

1. INTRODUCTION

The existing static allocation of the spectrum is a major hurdle for its efficient utilization. Current research concentrates on efficient allocation of the allotted spectrum without disturbing the licensed users [1-3, 36]. For efficient allocation of the unused spectrum, one must create algorithms to track the unused spectrum at any given time, location, and allocate to the needed users. The design requires appropriate detectors at the physical layer to sense and access the strategies at the MAC layer. If the traffic on the communication space is random, the fixed channel allocation method is inefficient. The flexible sensing policy helps better in the allocation of the channels to the most qualified user (s) while avoiding other competing users.

For efficient use of the spectrum, one must detect the spectrum holes. The main function of cognitive user (CU) is sense, manage, mobile, and share the spectrum. It is difficult to search and detect the unused channels. The CU has to use a strategy to sense and manage the unused spectrum (channels). Game models help to detect the unused spectrum (available channels) and in assigning appropriate channel to the cognitive user.

Detecting spectrum holes (unused spectrum) without any errors (false alarms) and then efficiently allocating the unused spectrum is a critical issue. Once the unused spectrum is detected, the cognitive user (CU) decides to transmit on a selected high utility channel based on detection analysis (outcome). Trusting the detector, minimizing the interferences, and avoid the collisions are part of the resource (spectrum) allocation problems. If the probability of detection accuracy is extremely high, then the channel will be allocated using the channel allocation policies. The channel allocation policy must avoid the collisions and interferences.

The secondary users (cognitive users) adopt several methodologies to identify spectrum holes, learn from current communication environment, and exploit the opportunities to grab the spectrum without disturbing the primary user. This means that the cognitive users can create flexible access to the spectrum. They can partition the spectrum into a large number of orthogonal channels and complete the transmission simultaneously with a flexible set of channels. Such partition can be designed using a distributed approach for dynamic spectrum access. The approach may use graph models, game theory models, or any other Artificial Intelligence related models that quickly adapt to the varying traffic demands. These models determine the number of channels to use and maximize user throughput. These strategies follow the local maxima and continue until they achieve global maxima.

To use the spectrum holes efficiently, we must create the spectrum sharing scenario where multiple secondary users (SUs) coexist in the same area and communicate with the same portion of the spectrum. The game models were tested in a share market related problems and currently introduced in wireless communications [4-8]. The spectrum sharing problem can be solved with the cooperation of economic models and the selfish motivation of game models. In cooperative and selfish environments, the CU (SU) must consider the presence of other SUs as well as primary users (PUs). In a cooperative environment, it is required to consider explicit communication between CUs [9] only. In the selfish environment, the SUs compete for the resources using machine learning models or game models [1, 10, 11, 36].

In recent years, the FCC has been promoting the technologies for the efficient utilization of the spectrum. The FCC's interest helped industries to introduce devices with various capabilities including frequency agility, adaptive modulation, transmit power control, and localization. Furthermore, the NeXT generation program of the Defense Advanced Research Program Agency

(DARPA) concentrated on technology based on using cognitive radios (CR) for efficient utilization of the spectrum. Therefore, dynamic spectrum access (DSA) became a promising approach for efficient utilization of the spectrum [12].

Dynamic spectrum access (DSA) is the sharing of existing spectrum by unlicensed users (secondary or cognitive users) with licensed users (primary users) without interference to the licensed users. Sharing of spectrum requires following certain rules and policies. Spectrum sharing rules and protocols that allow the bandwidth to share are discussed in [14]. The important point is the amount of information that the secondary systems or cognitive systems need to know to use the unused spectrum. The information includes the current state of other cognitive users accessing same resource, unutilized and underutilized spectrum.

The key component for DSA is the sharing the spectrum with efficient allocation of the unused spectrum resources and the scheduling these resources among the SUs. Identification of the unused spectrum is the main part of the resource allocation. CRs play a major role in sensing unused spectrum intelligently making the appropriate decisions to gain access to unused spectrum. Game models help to select the unused spectrum intelligently and bring above the appropriate outcome for efficient allocation of resources. Since multiple users are involved in the process, security becomes an important factor. Therefore, CRs have additional work to deal with selfish and malicious users.

There are many models developed including efficient channel utilization, channel modeling, and allocation of resources for underlay techniques [6, 15, 22]. Recently, the research is diverted towards the design of efficient models for overlay and underlay techniques. The game models are the new introduction for spectrum sharing and utilization and produces encouraging results [30, 6, 15, 22]. The researchers introduced the role of games and game models for efficient use of spectrum. Non-cooperative and congestion game models are more suitable to the overlay and underlay spectrum usage.

Some of the game models presently trying to apply for overlay and underlay spectrum are zero-sum games, non zero-sum games, potential games, cooperative games, non-cooperative games, and congestion games. The behavior and stability of game models is measured through Nash equilibrium. The fundamental is that the players must reach Nash equilibrium to provide stable condition. Some of the models are discussed below:

- The zero-sum game is played between two players. The net result of two players that equals zero means that the gain of one player equates the loss of another player. Zero-sum game is not useful in the current problem because we have to utilize available spectrum efficiently. There is no loss involved.
- The non-zero-sum game model can be used in overlay spectrum utilization because if one or more of the players (cognitive users) cooperate then some or all of the players will be benefited. In non-zero-sum game, the cooperation of secondary users helps for efficient use of spectrum.
- The potential function in game model is a useful tool to analyze equilibrium properties of games. In potential game, the incentive of all players is mapped into a single function called potential function. In finite potential games [12, 13], the change in any player's utility exactly matches by a change in potential which concludes that the Nash equilibrium is a local maxima. If we treat the total incentive as utilizing unused spectrum, we may use the potential games to find the unused spectrum and make it available to the cognitive users.
- In cooperative games, the players stay close together for the overall benefit of all players. In non-cooperative games, each player makes independent decisions. Any cooperation in the game is self enforcing. The cooperative game may be useful in the current problem of efficient utilization of spectrum.
- Congestion games [15, 16] are a class of non-cooperative games where players share a common set of strategies. The utility of a player in congestion games depends on using a resource with the players that are using the same resource. That is the resulting payoff is a function of the number of active users (congestion). The authors used the congestion game model for better utilization of the unutilized spectrum by cognitive users.

In this research, marketing models for rating of a channel, case-based reasoning and automatic collaborative filtering concepts were used to allocate the preferred channel to the SU. The concept of the cooperative game approach boosts the case-based reasoning and automatic filtering models in maximizing channel allocation to a prioritized SU.

The Contribution:

The contribution includes the design of the problem using game models with opportunistic access to the spectrum by secondary users at any given time slot. The reward and penalty for user action are introduced depending upon the channel gain by the SU. The problem solution is dealt with game model using the collaborative effort of SUs. The channel rating was obtained using a new approach called Sporas, Carbo, Molina and Davila (SCMD) method. The channel gain by SUs was explained using Algorithm SCMD. The algorithm was discussed using simulations with random data developed in the MATLAB language.

The remaining part of the document is organized as follows: The related work and recent developments are discussed in Section 2. The channel selection in Fuzzy environment was discussed in Section 3. The problem formulation for total reward was discussed in Section 4. Section 5 introduces the case-based reasoning and automatic collaborating filtering. Sections 6 and 7 discuss the cooperative game model and preference of a channel for secondary users. The algorithm and simulations using examples with sample data were discussed in Section 8. The Section 9 concludes the results and outlines the future research.

2. Related Work

The overview of the opportunistic spectrum access and taxonomy of dynamic spectrum access was provided by Zhao et al. [13]. Zhao et al. explained the confusion of the broad term CR as a synonym for dynamic spectrum access (DSA) and provides the clear distinction between the spectrum property rights, dynamic spectrum allocation, ultra wide band (spectrum underlay) and opportunistic spectrum access (spectrum overlay). Spectrum overlay (opportunistic spectrum access) and spectrum underlay techniques are also used for efficient allocation of the spectrum [31, 33]. Hidden Markov model to predict the primary user and efficient use of unused spectrum was discussed in [32]. Le and Hossain developed an algorithm for underlay and the quality of service (QoS) in code division multiple accesses (CDMA) with minimal interference was discussed in [34].

Efficient allocation of unused spectrum through auction, bidding, and rating was discussed in [1, 8, 19, 31, 32. The research contributions include the economic, game theory, stochastic, case based reasoning, Markov, and hybrid models for efficient allocation of unused spectrum. Auction-based dynamic spectrum allocation and lease the spectrum to CUs was discussed in [8]. The congestion game model for maximizing the spectrum utilization by secondary users with minimal interference to primary users was discussed in [31]. The Hidden Markov Models using Baum-Welch procedure to predict the future sequences infrequency and use them in computing the channel availability was discussed in [32]. The spectrum bidding behaviors and pricing models that maximize the revenue and better utilization of the spectrum was discussed in [19]. The market-based overlay model discussed in [7] imposes the spectrum mask to generate the better spectrum opportunities to secondary users. Furthermore, for efficient usage of unused spectrum, the primary user uses the economics competition for purchase of power allocation on each channel. This economic model uses the market equilibrium while controlling the interferences. The real-time spectrum auctions discussed by Gandhi et al. [19] include spectrum bidding behaviors and pricing models. The model discusses the spectrum demands and how to maximize the revenue for efficient utilization of the spectrum.

The recent developments for efficient utilization of spectrum holes include the role of cognitive radio using economic, game, stochastic, and Markov decision process models [14-18]. The auction-based dynamic spectrum allocation to lease the spectrum by secondary users was discussed by Wu [8]. In their paper, they proposed a mechanism called “multi-winner spectrum auction with a collision resistant pricing strategy” to allocate the spectrum optimally. The greedy algorithm proposed by Wu helps to reduce the complexity in multi-band auctions.

The game models for spectrum sharing and controlled interference is studied in [9, 20 -22]. Nie et al. [20] formulated the channel allocation as a potential game and showed the improvement of the overall network performance. Ji et al. [21] discussed the dynamic spectrum sharing through the game theory approach and discussed the analysis of the networks, the user’s behavior, and the optimal analysis of the spectrum unused allocation. Halldorsson et al. [22] viewed channel assignment as a game and provided the price anarchy depending upon the assumptions of the underlying network. Finally, Liu et al. [9] used the congestion game model for spectrum sharing and base station channel adaptation.

In the current research, we introduced the opportunistic channel access by secondary users represented by a tuple consisting of a number of users contesting, the resources available, and the strategies used by the users that create an objective function (utility function). Whenever a user tries to gain an action to a channel, three cases arise. The user request is often accepted, denied, and the user has no action. The award or penalty depends after acceptance of the user request.

We further introduced the cooperative way of gaining a channel using SCMD model. These two models help to gain the channel access with the help of user’s previous experience which includes channel weight and channel rating. The preference is calculated using nearest neighbor algorithm and/or mean square difference formula. These two formulas were used with users’ cooperation activity. The cooperative activity includes their channels rating and user preferences. Using these concepts, the SU demands will be fulfilled.

3. Channel Selection in Fuzzy environment

Efficient allocation of the spectrum requires the coordination among the cognitive users (CU). The cognitive users prefer the high-rated spectrum. The high-rating depends upon the spectrum in demand. The high reputation of the spectrum is the measurement of demand. The reputation of the spectrum is the continuous rating by users. Sporas formula can be used for updating the reputation of the spectrum and CMD (Carbo, Molina and Davila) formula for updating fuzzy ratting. The rating of the spectrum with loosely connected agents (cognitive users) is given in the following formula [3].

$$R_i = R_{i-1} + \frac{1}{\theta}\phi(R_{i-1})(C_i - R_{i-1}) \tag{1}$$

$$\phi(R_{i-1}) = 1 - \frac{1}{1+e^{-(R_{i-1}-D)/\sigma}} \qquad (2)$$

where:

θ - effective number of ratings taken into account $(\theta > 1)$. The change in rating should not be very large.

ϕ - helps to slow down the incremental change

C_i - represents the rating given by the node i

D - range or maximum reputation value

σ - the acceleration factor to keep the ϕ above certain value (> threshold).

If the rating of the channel falls below the required threshold value ($(C_i - R_{i-1}) < 0$) then cognitive users will not request that channel. That is, the current channel cannot provide Quality of Service (QoS). The Sporas formula was used to rate the channel and verify the current rating. Initially $C_i - R_{i-1}$ was selected as positive and made C_i as random and > 0.9. The Figure 1 show the channel rating increases initially and falls down later, since the value of $C_i - R_{i-1}$ becomes negative at later time. We assumed the following arbitrary values for simulations to calculate the channel ratings.

θ=45; Ci > 0.9 (taken as random);

D=0.95; σ =0.3

R_{i-1}=0.95

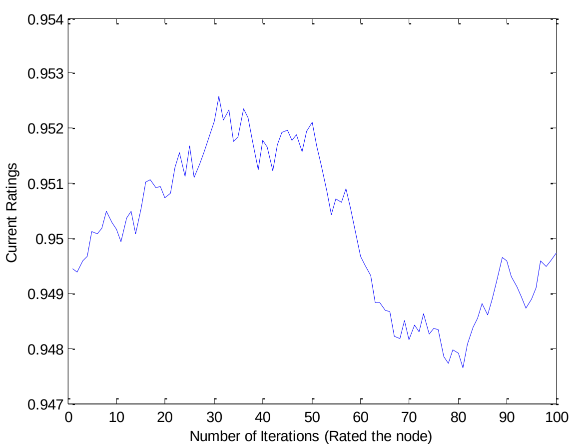

Figure 1: Channel Ratings using Sporas formula

Sporas formula calculates the ratings of a channel using the previous ratings. We have taken θ value bigger to observe the change of ratings of channel slowly.

The channel ratings are provided by the user. The ratings may be vague, uncertain, and incomplete. Representing such information in nature is fuzzy. The ratings of the channel are continuously changing through user supply information. The recent ratings (reputation of the channel) are modified (increase or decrease) using the user supplied approximate ratings. Therefore, current ratings depend upon the previous ratings.

Let R_{i-1} be the rating of the channel at $(i-1)^{th}$ instant and Z_i be the rating currently provided by the user after completion of the channel usage at instant i. The new reputation of the channel depends upon these values Z_i and R_{i-1}. The previous value will be used depends upon the learning factor ζ. Therefore, the reputation of the channel can be computed using the CMD formula [4, 5] as below.

$$R_i = \frac{R_{i-1}.\zeta + Z_i.(2-\zeta)}{2} \qquad (3)$$

If the learning factor $\zeta = 0$ means that the current rate is same as previous rate. If the learning rate $\zeta = 1$ means that the channel rate is constant. The learning rate will be updated each time by a factor δ using the Sporas formula. The update of learning factor is given as:

$$\zeta = \frac{\zeta + \delta}{2} \qquad (4)$$

The value for δ is provided through Sporas formula from equation (1). The channel rate will be increased or decreased depending upon the current value ζ. Figure 2 shows the comparison of the channel ratings using Sporas formula, the fuzzy reputations using CMD formula, and CMD formula with learning updates using Sporas formula. The use of Sporas formula or CMD formula will not provide the stable ratings. Further, if updating the learning factor with Sporas formula, the channel rate will become stable quickly. The Figure 2 concludes that the best channel rate will be obtained with the combination of the recommendation process of CMD and learning updates with Sporas formula. The Figure 2 concludes that the Sporas formula or CMD formula will not provide the stable ratings of the channel. The combination of these two models (hybrid model) will provide acceptable recommendation. The cognitive user will have a better choice if the user gets stable rating rather than vague ratings.

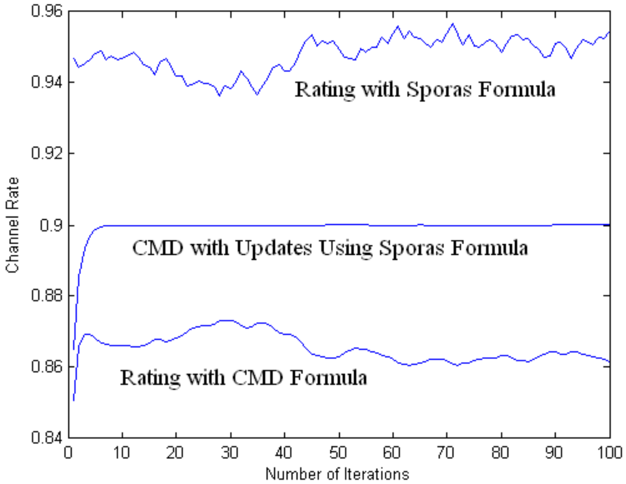

Figure 2: Comparison of Channel ratings (Sporas, CMD, and CMD& Sporas

4. Problem

Let P denote the primary user (PU) and S denote the secondary users (SU). There are N primary users and M secondary users. Each primary user P_i $(i=1...N)$ has bandwidth $B_i(i=1,...,N)$ and secondary user S_i $(i=1...M)$ competes along with other secondary users $S_{j,j\neq i}$ in the network to gain access to unused spectrum by PUs. The SU or cognitive users (CU) compete for the spectrum during sleeping time (unused time) of PU. The available spectrum slots depend upon the geographical locations. Each SU competes for spectrum and sense it at the beginning of each time slot.

The availability of j^{th} primary channel $(j=1...N)$ for i^{th} secondary user $(i=1...M)$ depends upon the probability of the channel availability and the opportunistic access by the i^{th} SU. Suppose, there are κ primary channels available to M secondary users competing at any given time slot t, then each SU has chance to obtain the channel at time slot t is κ/M. Therefore, the opportunity for the i^{th} SU to access the κ available primary channels at any time slot t is

$$S_i^k(t)=\kappa/\mathrm{M}=K\text{, for } i\in M$$

The total opportunities for all secondary users at any time slot for κ available primary channels is

$$\sum_{i=1}^{M}S_i^k(t)=\sum_{i=1}^{M}K_i(t) \text{ and } t\in T \text{ the time unit.}$$

The opportunistic channel access is represented by the tuple (S,K,Π,U), where S is the set of SUs competing for resources K $(k_i\in\mathrm{K})$ which is a set of channels available to SU at any given time slot t, and each SU uses the strategy $\pi\in\Pi$ that generates the utility $u\in U$. For each action of the secondary user S_i, the user senses the spectrum with a strategy π_i. The sensing action may get success/fail with reward R_i which is 1 or -1. The channel access tuple can be represented as a game, where each SU in the game uses a strategy to compete for the resource called spectrum that costs for gaining the specific utility as the object function. During the process the SU may gain or lose the opportunity and generate the reward or penalty. Therefore, the game model G is represented as

$$G=\{S,\mathrm{K},\Pi,U\} \tag{5}$$

The total benefits are the sum of all gains minus the sum of all penalties. Therefore, the total reward $\Re$ is given by

$$\Re=\Lambda\sum_{i=1}^{M}\sum_{t=1}^{T}R_i^t \tag{6}$$

and Λ is a constant $0\leq\Lambda\leq1$.

$$R_i^t=\begin{cases}1 & \text{if user } i \text{ gains resource with strategy } \pi_i \text{ at time slot } t\\ 0 & \text{for no action}\\ -1 & \text{if user } i \text{ fails to obtain the resource at time slot } t\end{cases} \tag{7}$$

The sensing policy of the cognitive user decides the action to be taken at a given time slot. Once the channel is sensed as free then the allocation policy decides which secondary user has priority to gain access. The average reward per time slot (T) is calculated as $\Re/T$ and will be used for throughput criteria.

The channel gained by the SU depends upon the current state and policy of the assignment that maximizes the total reward. Therefore, the channel assignment to the SU depends upon probability of availability of a channel and the probability of getting a channel. The probability of availability of a channel to a SU at any time slot t is

κ / M and the probability of assignment of the channel will be obtained by using the SCMD [23 - 25].

5. Case-Based Reasoning and Automatic Collaborative Filtering

In the selection of a product, CBR is used when experts find it hard to articulate their thought processes because the knowledge acquisition for these cases would be extremely difficult to such domains and is likely to produce incomplete or inaccurate results. CBR systems allow the case-base to establish characterized cases incrementally. Therefore, the case of SU is established incrementally for priority policy. A widely used formula for CBR in identifying and recommending similar channels (spectrum) is the nearest neighbor retrieval, which is based on weighted Euclidean distance [35].

The nearest neighbor algorithm deals with the similarity between the priority of stored cases (channels) and newly available cases (channel). The outcome depends upon the matching of the weighted sum of features. The toughest problem is to determine the weights of the features of the resource (spectrum). The limitation of this approach depends upon the converge to the correct solution and retrieval times. A typical algorithm for calculating the nearest neighbor (matching) is the one used by Cognitive Systems Remind software reported in Kolodner [24]. The nearest neighbor algorithm with weight of a i^{th} feature (w_i), similarity function sim, input case of i^{th} feature f_i^I, and retrieval case of i^{th} feature f_i^R is given by (Φ) [24]:

$$\Phi = \frac{\sum_{i=1}^{n} w_i \times sim(f_i^I, f_i^R)}{\sum_{i=1}^{n} w_i} \qquad (8)$$

Equation (8) calculates the nearest neighbor of the best channel from the available channels of SU. If the difference between the i^{th} and j^{th} feature is negligibly smaller than the two features are closely matched. Equation (8) calculates the highly rated and close matching interests of the i^{th} user channel. The selection will be compared with ACF. The final selection will be the combined result of ACF and CBR.

Automated collaborated filtering (ACF) is a recommendation of a product based on word of mouth. In ACF, if user A's ratings of a channel (or channels) matches with another user B's ratings then it is possible to predict the ratings of a new channel for A, if B's rating for that channel is available. In other words, let us assume that if users X, Y, and Z have common interest in the channels C1, C2, and C3, then if X, Y did high rate of channel C4, then we can recommend the C4 for Z. That is, we can predict that user Z bids high for that channel C4, since C4 is close interest of Z. The approximate bid of a kth bidder can be calculated by storing the bids of current bidders on the spectrum.

The ACF uses the mean squared difference formula [27] with two users. Let U and J be two SUs interested in a channel. Let U_f and J_f be the ratings of U and J on a feature f of the channel. Let χ be the set of features of the channel. Both U and J are rated and $f \in \chi$. The difference between two persons U and J in terms of their interests on a channel is given by [27]:

$$\Delta = \delta_{U,J} = \frac{1}{|\chi|} \sum_{f \in S} (U_f - J_f)^2 \qquad (9)$$

The ACF recommendations are two types, invasive and noninvasive based on the user preferences [1, 28, 29]. An invasive approach requires explicit user feedback, where the preferences can vary between 0 and 1. In the noninvasive approach, the preferences are interactive and Boolean values. In the noninvasive rating, zero (0) means the user does not rate the item and one (1) means rated. Therefore in noninvasive cases, it requires more data for any decision. In ACF systems, all user recommendations are taken into account, even though they are entered at different times. More user recommendations provide good strength for the ACF recommendation system and the new recommendations solely depends upon the data.

6. Cooperative Game Model

The secondary users rate the spectrum after the use. The rating will be updated (on a channel or spectrum) using SCMD. At a later time, the ratings will help the CUs to select appropriate spectrum to match their requirements. In the same way, the users rate the spectrum after they use in cooperative game model.

In cooperative games, the competition between coalitions of players groups the players and enforces cooperative behavior. The players choose the strategies by a consensus decision making process. It is assumed that each player has more than one choice. The combination of choices may win/loose/draw with an assigned payoff. The players know the rules and select the higher payoff. The payoff will be calculated using equation (7) and the channel selection with equations (8) and (9). This concludes that the channel selection will be done using the CBR and ACF models and cooperative behavior of the players.

The assignment of the channel to SU will depend upon the characteristic function ν as defined below:

Definition 1: The tuple (M, ν) is a cooperative game only if ν is monotone. This concludes that the cost assignment is positive. That is, $\nu(S) \leq \nu(S')$ for all $S \subseteq S' \subseteq M$.

The channel preferences can be arranged monotonically using the definition 1, equation (4), and equation (5). The SU will then choose the best choice from the available channels. For example, let us consider the similar interest SUs into a sub group S' where $S' \subseteq S$. The similar interest SUs on a particular available channel needs the priority of these users. The best available channel that will be calculated using equation (4) and equation (5) then provide the difference between two users in terms of their interest. Therefore, it is easy to assign the closely matching channel to one of the SU.

In a cooperative game, an allocation is simply a overall value created and received by a particular user. For example if x_i for $i = 1,2,3...n$, a collection of values related to a channel, then the allocation is efficient if x_i is in $\nu(S)$. That is

$$\sum_{i=1}^{n} x_i = \nu(S).$$

This shows that each player (SU) must get as much as they need without interacting with other users. The creation of quantity $\nu(S)$ means the efficiency of its created values and gain of access to the appropriate channel by a SU.

Definition 2: The marginal contribution of a player is the amount of the overall value created and the value shrinks if that player has to leave the game.

Therefore, in a collaborative effort, marginal contribution members deduce something about the overall contribution to a particular game. This is a justification for a cooperative game related to users' contribution and leads towards the justification of channel selection.

7. Preference of the Channel

Let us assume that there are four SUs, rated using eight channels that were used before. The weights are the user ratings and the preferences are the similarity function sim. The sim is based on availability and retrieval (preference). Let the preference selection rate vary as $0 \le sim \le 1$. Similarly, the user rating (weight) also varies $0 \le w_i \le 1$. The preference of a channel is calculated with randomly selected values as in Table I. The Table 1 uses the abbreviations as below:

U# = User number
C# = Channel Number
CR = Channel Rating
CRR = Channel Retrieval Rate
w = weight assigned to channel
sim = Average weight

TABLE I: SPECTRUM BIDDING WITH N CHANNELS AND K USERS

U #	C#	CR	CRR	sim	w
1	1	0.5	0.6	0.55	0.6
2	2	0.4	0.4	0.4	0.5
1	4	0.6	0.5	0.55	0.5
4	3	0.8	0.7	0.75	0.7
3	5	0.2	0.3	0.25	0.3
2	8	0.5	0.6	0.55	0.6
1	7	0.8	0.8	0.8	0.9
2	6	0.6	0.6	0.6	0.7

The Φ value in equation (4) is for the nearest neighbor. The calculations are provided in table I and the Φ value is given by:

Φ =0.6948

Therefore, the channels closest and greater than the Φ value will have a better choice of the selection by the SU. In the above table, the channels 3 and 7 have primary choice and channels 1, 4, 6, and 8 will get second choice for selection. Channel 5 has low priority.

In the case of ACF, we will consider the interest of two users on a particular channel and their ratings. In this case, we will look into the quality of service (QoS) and ratings on a particular channel by the two users. The interest factor will be calculated using the channel features called QoS and Ratings as shown in Table II.

TABLE II CHANNEL RATING BY TWO USERS FOR PREFERENCE

User#	Rating	QoS	χ
1	0.7	0.8	0.9
2	0.8	0.75	0.9

Using the difference formula in equation (5), and the data from Table II, the Δ value is calculated and is given by:

Δ = 0.0139

In the current case, since the difference between the interests of two users is close to 1%, the two users will bid for the channel. The highest bidder wins the channel or highest preference by the priority allocation will get the channel. The preference (priority) may be a hand-shaking situation, where a user is moving from one access point to another. Therefore, in the current channel allocation the cooperative games use the economic model for preference and allocation of the channel. The characteristic function is based on CBR or ACF model.

8. SIMULATIONS

We will discuss the efficient utilization of spectrum by secondary users by gaining a preferred. The following algorithm CBR-ACF calculates and assigns the appropriate channel using priorities to SUs at any given time.

Algorithm CBR-ACF

a) Find available channels (generate randomly)
b) Use the nearest neighbor algorithm (CBR) and
   - find the channel (s) closest to user1 preference
   - find the channel (s) closest to user 2 preference
c) Using ACF formula find the user preferences for the same available channels between two users
d) Assign the channel using CBR and ACF data
e) Repeat the steps (a) to (d) for another user

The Algorithm CBR-ACF selects the channel closest to the user choice. If more than one user is interested in the same channel, then the system must select the preferred user.

The simulations were conducted using random data. The program was written in MATLAB. In the current case, we assumed 99 channels. The values for CR, CRR, and w were assigned using a random function. The sim values are calculated for each channel. Many simulations were conducted and recorded for key explanation of algorithm CBR-ACF.

Case 1

The following data was obtained using the Algorithm CBR-ACF and equations (4) and (5). Basing the simulations data, we concluded the current available channel will be allocated to the preferred user.

Φ =0.5079

Free channels: 51 8 6 63 62

Preferred channel: 51

Preferred CRR for this channel: 0.5136

ACF for this channel calculated for 3 user cases:

User1 ACF = 0.0241

User2 ACF =0.0378

User3 ACF =0.0295

According to this data user 1 will be assigned the channel 51.

Case 2

Φ =0.4769

Free channels: 71 50 47 6 68

Preferred channel: 6

Preferred CRR for this channel: 0.4218

ACF for this channel calculated for 3 user cases:

User1 ACF = 0.0381

User2 ACF =0.0298

User3 ACF =0.0542

According to this data user 2 will be assigned the channel 6.

For example, consider the case 2; the CBR assigns the available channel to user 1 with its priorities. The priorities are calculated using the closest matching of ratings and combined decision using CBR and ACF. The decision is the collaborative since the outcome was used users' priorities and recording their suggestions through weights, channel ratings, and priorities. We are working on the reward and penalty depending upon the assignment. We are also working on the bidding policy, when two users are closely matches for request.

9. CONCLUSION

Recent developments show that the there are different approaches for the efficient utilization of the spectrum. The approaches include genetic algorithms, neural networks, stochastic models, game models, and economic models. These models are used display the by dynamic spectrum access concept as a catalyst for efficient utilization of unutilized and underutilized spectrum. The channel-gain in an opportunistic and collaborative way is also a part of efficient utilization of the spectrum. In the current research, we introduced a new approach using case-based reasoning and automatic collaborative filtering with the cooperative game approach. The combination brings the cooperative game concept in the selection of a channel. The research was presented as a basic game model and channel gain by the SUs. The channel assignment to SUs was done by using the CBR and ACF models. These approaches were demonstrated using examples through a proposed Algorithm CBR-ACF.

The future work involves the identification of preferred SUs using reward and punishment model. Furthermore, automatic collection of spectrum holes and prioritizing the SUs using economic and biological models will save time in the fast allocation of channels to SUs. Automatic prioritizing also saves time and improves the quality of channel assignment (to a preferred and needed user).

Acknowledgment

The research work was supported by Air Force Research Laboratory/Clarkson Minority Leaders Program through contract No: FA8650-05-D-1912. The author wishes to express appreciation to Dr. Connie Walton, Grambling State University, for her continuous support.

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