International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Dig. Sys. 8, No.4 (July-2019)
http://dx.doi.org/10.12785/ijcds/080311

A Novel Hierarchical Fuzzy Systems Based Cooperative Spectrum Sensing and Opportunistic Spectrum Access Techniques

Ammar Abdul-Hamed Khader[1], Jassim M. Abdul-Jabbar[2], Rabee M. Hagem[3], Mainuddin[4] and Mirza Tariq Beg[5]

[1,2,3] Computer Engineering Department, University of Mosul, Mosul, Iraq
[4,5] Department of Electronics & Communication Engineering, Jamia Millia Islamia, New Delhi, India

Received 11 Feb. 2019, Revised 29 Mar. 2019, Accepted 28 May 2019, Published 1 July 2019

Abstract: When a large number of cognitive users (CUs) are competing for the spectral resource sharing with different parameters, it is a challenging job to decide a scheduling criterion to be followed and to solve the problem of idle channel allocation. This paper proposed a novel two levels Hierarchical Fuzzy Systems based cooperative spectrum sensing (level 1) and opportunistic spectrum access (level 2). Three separate groups of hierarchical fuzzy systems has been designed to estimate the probability of presence of three primary users (PUs) in first controller level and then estimate the percentage ratio of allocating idle channels to three out of nine CUs in second controller level. To improve the performance of this system during mobility state of PUs and/or CUs, a Hopping System module is proposed. The CUs nodes dynamically coordinate their action to detect all the bands sequentially in organized manner. The results indicate that fuzzy logic can be used in cooperative spectrum sensing to provide additional flexibility in decision making. While in opportunistic spectrum access, fuzzy logic allow the CU with highest possibility of spectrum access to occupy the idle channel and improve the probability of detection in mobility state by using hopping code.

Keywords: Cognitive Radio (CR), Primary User (PU), Secondary User (SU), Cognitive User (CU), Hierarchical Fuzzy Systems (HFS), Cooperative Spectrum Sensing (CSS), Opportunistic Spectrum Access (OSA) and Hopping System (HS).

1. INTRODUCTION

The requirements of the end user for wireless traffic has increased in a continuous fashion, hence the radio spectrum has become a limited resource, as elucidated by the recent spectrum identifications for the mobile service. In fact, the availability of new spectrum for sole primary allocation to mobile service is by itself challenging, due to the lack of unallocated spectrum support. Thus, new radio spectrum made available for mobile communication systems is likely to be shared with other systems, which calls for the development of efficient spectrum sharing techniques [1,2].

Dynamic spectrum access (DSA) techniques have been developed for efficient utilization of regulated spectrum. In DSA, secondary users (SUs) or cognitive users (CUs) (who have no spectrum license) can be allowed to use un-utilized licensed spectrum temporarily in opportunistic manner. However primary users (PUs) retain priority in using the spectrum. Cognitive Radio (CR) is a technology that makes use of DSA to utilize the spectrum more efficiently in an opportunistic fashion without interfering with PU [3,4].

The technology of CR takes advantage of the holes in the spectrum by identifying them intelligently and using them, then releasing it when required by the PU. CR is able to adapt its transmission on the unlicensed frequency band intelligently such that the interference to the PUs is avoided or limited to an acceptable level. CR is a new communication paradigm to fully utilize the scarce spectrum resources in an opportunistic manner [5,6]. This technology is categorized into four stages comprising, spectrum sensing, spectrum management, spectrum sharing, and spectrum mobility. During the first stage, unused spectrum is detected and shared, taking care to avoid harmful interference with other users. The management of spectrum captures the best available spectrum to meet user communications requirements.

E-mail address: ammar.khader@uomosul.edu.iq, drjssm@uomosul.edu.iq, rabee.hagem@alumni.griffithuni.edu.au, mainuddin@jmi.ac.in, mtbeg@jmi.ac.in

In the spectrum mobility stage and in order to have better spectrum availability, seamless communication during the transition is maintained. This stage ensures fair spectrum scheduling among coexisting users [7-9].

Adaptive resource management by fuzzy reasoning has been analyzed on several varied issues related to spectrum sensing and dynamic spectrum sharing strategies and models but relatively little works has been reported in open literature for SU scheduling using Fuzzy inference procedure [10-15]. Fuzzy logic system (FLS) is a quaint technique spatially in case where main problem is hardly modeled with conventional methods that solved mathematically but at the same time it's simple for human being to understand. The rule based decision based on fuzzy logic (FL) enables the efficiently inclusion of incomplete information. In addition, it provides saving in computational complexity. FL has been already proposed for use in telecommunication system, e.g., for quality of service routing in wired networks, decisions of route caching in wireless ad hoc networks, management of radio resource and selection of channel in cellular networks [16,17]. To overcome the problem of "curse of dimensionality" which means increase complexity with the number of input variables, a Hierarchical Fuzzy Systems (HFS) was introduced by [18]. HFS system has also been used in the opportunistic cognitive radio model for spectrum management strategy [19]. HFS consists of hierarchical number of low dimensional sub fuzzy systems called fuzzy logic modules instead of using high dimensional standard fuzzy system. These smaller fuzzy logic modules contribute to the final solution. The upper fuzzy subsystem may also take input as a combination of lower level output and an original input variable. Thus the HFS may have multiple levels and multiple sub systems at each level. In HFS, the total number of rules increases linearly with the increase in number of input variables as against exponential growth in standard fuzzy subsystem. The opportunistic spectrum access via periodic sensing has also been discussed by Zhao, et al [20], where framework of constrained Markov decision 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 in [21].

Many researches deal with spectrum access like [22-27] and more. They depend on designing FLS input's parameter on (Distance between PU and SU, and the Mobility of SU). But the problem in determining these parameters correctly, they:

(1) Assumed the transmitted signal power (Pt), power gain g(D) between PU and SU, the noise power σ^2 and SNR (γ) at the SU to be able to calculate the distance (D), as given in equation (1) below [24]:

$$\gamma = 10\log\left(\frac{Pt\ g(D)}{\sigma^2}\right) \quad \dots\dots\dots..(1)$$

(2) Or they depend on calculating the transmitted power Pt, on assuming that the SU is able to determine the data rate (R bit/sec) of PU. R is used to calculate its SNR as in equation (2), and consequently an estimation of PU transmission power Pt.

$$\frac{S}{N} = \frac{E_b}{N_o}\frac{R}{B} \quad \dots\dots\dots\dots(2)$$

Where S/N is the SNR value, S is the received signal in watts (w) and N is thermal noise power (w), E_b is energy of a single bit of information in joule, N_o is noise power density (W/Hz) and B is the minimum bandwidth required for a particular modulation scheme for transmission [25]. Pt is obtained and compared with the received power (Pr) at SU to decide the distance between PU and SU as in equation (3):

$$\Pr(d) = \frac{Pt.Gt.Gr.\lambda^2}{(4\pi)^2\, d^2 L} \dots\dots\dots\dots(3)$$

where Pr(d) is the received power, Pr as function of transmitter and receiver separation distance d in meters, Gt and Gr are transmitter and receiver antenna gain respectively, L is the system loss factor not related to propagation ($L \geq 1$) and λ is the wavelength in meters.

In this paper we propose a novel three branches of Hierarchical Fuzzy Systems (HFS), each HFS consists of two layers. Design of first layer is basically a FLS based cooperative spectrum sensing (CSS) technique to determine the **Probability of PU Present** (Pro. PU Pre.) by collecting information cooperatively from three spatially displaced CUs nodes, where the cooperative decision making process is implemented using rule based FLS. In second layer a 36 rule based FLS is designed to control the opportunistic spectrum access (OSA) and to determine the **Possibility of Allocating** (Poss. of Allo.) idle channel to a selected CU depends on four descriptors: (i) (Pro. PU Pre.) that fed from the output of first controller; (ii) **Waiting Time** (W.T.) of every SUs waiting for occupy the idle channel; (iii) the **SU Power** (SU P.) and (iv) **Percentage Ratio of Spectral Utilization** (% Spec. UT.) of SU from overall available spectrum. We introduce a Hopping System (HS) module before FLS to arrange the cooperative spectrum detection process that done by multiple CUs. This module allows only three CUs out of nine to sense a band of interest at a time, then one of these three CUs will changed sequentially by another new CU, so that all the nine CUs will go through checking all the bands in one periodic cycle. For the case of HS module that proposed here and added before the FLS, it is the first time happened in the literature as the knowledge of the authors.

2. System Description

A fuzzy based approach is proposed to define the spectrum access possibility of nine unlicensed users (SUs) in a context characterized by uncertain and incomplete information from three PUs. We propose three separate branches each of them consists of two levels Hierarchical Fuzzy Systems (HFS) to achieve CSS in first level and OSA in second level because there are three PUs.

In each branch the first controller in first level is used to estimate the presence or absence of PU i.e. CSS and the second controller in second level receives the output of the first controller as an input along with three other antecedents (W.T., SU P. and Spec. UT.); to determine finally the possibility of allocating the idle spectrum to unlicensed user i.e. OSA.

A. CSS Based FLS

In cooperative spectrum sensing the decisions of the presence of the primary user are based on observation results from several cognitive radio nodes. The individual nodes report their decisions to a fusion centre that combines the decisions with some rule (AND, OR or majority combining). The reporting of only the decisions instead of the individual measurements requires less signalling. In general the combining rule for cooperative spectrum sensing is “n out of M rule” that can be presented as [16]

$$D = \sum_{n=1}^{M} D_m \begin{matrix} \geq & n: & \text{signal present} \\ < & n: & \text{signal absent} \end{matrix} \quad \ldots\ldots\ldots (4)$$

where D_m is the decision of the m^{th} cooperative cognitive radio node, (number zero or one denoting signal absent or present respectively), M is the number of the cooperative nodes, and n is the number of users that is set as the threshold. From (4) we can obtained rules as AND, OR and majority combining by setting n = 1, n = M, or n = M/2 that means PU is declared present if one node, all nodes, or most of the nodes detect the PU. In our design M=3 and n=M/2.

To test the feasibility of fuzzy logic for the mathematical cooperative spectrum sensing combining schemes given in (4), a simple fuzzy decision making algorithm for decision fusion for the case of three cooperative cognitive radio nodes has been designed. The fuzzy combining scheme is constructed using basic methods in fuzzy reasoning and defuzzification. This scheme takes as an input the decisions from the individual cooperative cognitive radio nodes and produces as an output the combined sensing result, i.e., PU present or absent.

The developed fuzzy system includes three inputs with three Membership Functions (MBFs) each and one output with three MBFs. The names of the input MBFs describing the strength of the individual sensing nodes' decisions are low, med and high indicating the likelihood of the presence of PU signal. The names of the output MBFs describing the strength of the combined sensing result are low, med, and high indicating the combined likelihood of the presence of PU signal.

An independent and identically distributed (i.i.d) lognormal Rayleigh fading channel with AWGN channel between a PUs and SUs is assumed. Each SU conducts energy detection and transmits the received signal power in perfect control channel to fusion centre.

We used here Mamdani fuzzy rule because this type of rule based fuzzy system provides a normal framework to include expert information in the form of linguistic rules [16]. These information can easily be combined with rules that describe the relation between the input and output of the system. Also, Mamdani rule based type has a high degree of freedom to select the most suitable fuzzification and defuzzification interface components as well as the interface method itself [28].

Based on the sensing results combined from different SU nodes, the first fusion centre makes the final decision regarding the presence or absence of the PU.

If $T_n[k]$ for n=1,2,…,N represents the received signal power of n^{th} SU at time instant k and hypotheses H0 and H1 denote the absence and presence of a primary signal respectively, then the signal power received by n^{th} SU is given by:

$$T_n[k] = \sum_N (Y[n])^2 \quad \ldots\ldots (5)$$

Then H0: $Y[n] = W[n]$ signal absent ………….. (6)

H1: $Y[n] = X[n]\,H[n] + W[n]$ signal present …… (7)

where X[n] is the primary signal, H[n] denotes the channel gain between the PU and the n^{th} SU and W[n] is the additive white Gaussian noise (AWGN) [29].

The rules are of the form IF X_1 is A_{1a} AND X_2 is B_{2a} AND X_3 is C_{3a} THEN Y_1 is D_{1y} , where A_{ia} , B_{ia} , C_{ia} and D_{iy} are linguistic labels of variables X_i and Y_i used in the rules respectively. The number of rules in 1st level HFS is 27. Table I presents all combinations of the rules.

B. OSA Based FLS

We design a FLS to solve the opportunistic spectrum access problem in cognitive radio network in 2nd level HFS. The best suitable secondary user to access the available band is collected based on the following four antecedents, (descriptors):

TABLE I. RULE BASE TO DETERMINE PRO. OF PU PRE.

SN	PU1	PU2	PU3	PRO. PU PRSENT
1	LOW	LOW	LOW	LOW
2	LOW	LOW	MEDIUM	LOW
3	LOW	LOW	HIGH	LOW
4	LOW	MEDIUM	LOW	LOW
5	LOW	MEDIUM	MEDIUM	LOW
6	LOW	MEDIUM	HIGH	MEDIUM
7	LOW	HIGH	LOW	LOW
8	LOW	HIGH	MEDIUM	MEDIUM
9	LOW	HIGH	HIGH	MEDIUM
10	MEDIUM	LOW	LOW	LOW
11	MEDIUM	LOW	MEDIUM	LOW
12	MEDIUM	LOW	HIGH	MEDIUM
13	MEDIUM	MEDIUM	LOW	LOW
14	MEDIUM	MEDIUM	MEDIUM	MEDIUM
15	MEDIUM	MEDIUM	HIGH	HIGH
16	MEDIUM	HIGH	LOW	MEDIUM
17	MEDIUM	HIGH	MEDIUM	HIGH
18	MEDIUM	HIGH	HIGH	HIGH
19	HIGH	LOW	LOW	LOW
20	HIGH	LOW	MEDIUM	MEDIUM
21	HIGH	LOW	HIGH	MEDIUM
22	HIGH	MEDIUM	LOW	MEDIUM
23	HIGH	MEDIUM	MEDIUM	HIGH
24	HIGH	MEDIUM	HIGH	HIGH
25	HIGH	HIGH	LOW	MEDIUM
26	HIGH	HIGH	MEDIUM	HIGH
27	HIGH	HIGH	HIGH	HIGH

TABLE II. RULE BASE TO DETERMINE POSS. OF ALLO. CH.

SN	PRO. PU PRSENT	W.TIME	SU POWER	SPE. UT. %	OUT POSS.
1	LOW	LOW	LOW	LOW	MIDEUM
2	LOW	LOW	LOW	MEDIUM	MEDIUM
3	LOW	LOW	LOW	HIGH	LOW
4	LOW	LOW	HIGH	LOW	HIGH
5	LOW	LOW	HIGH	MEDIUM	HIGH
6	LOW	LOW	HIGH	HIGH	MEDIUM
7	LOW	HIGH	LOW	LOW	VERY HIGH
8	LOW	HIGH	LOW	MEDIUM	VERY HIGH
9	LOW	HIGH	LOW	HIGH	HIGH
10	LOW	HIGH	HIGH	LOW	VERY HIGH
11	LOW	HIGH	HIGH	MEDIUM	VERY HIGH
12	LOW	HIGH	HIGH	HIGH	HIGH
13	MEDIUM	LOW	LOW	LOW	LOW
14	MEDIUM	LOW	LOW	MEDIUM	LOW
15	MEDIUM	LOW	LOW	HIGH	VERY LOW
16	MEDIUM	LOW	HIGH	LOW	MEDIUM
17	MEDIUM	LOW	HIGH	MEDIUM	MEDIUM
18	MEDIUM	LOW	HIGH	HIGH	LOW
19	MEDIUM	HIGH	LOW	LOW	HIGH
20	MEDIUM	HIGH	LOW	MEDIUM	HIGH
21	MEDIUM	HIGH	LOW	HIGH	MEDIUM
22	MEDIUM	HIGH	HIGH	LOW	HIGH
23	MEDIUM	HIGH	HIGH	MEDIUM	HIGH
24	MEDIUM	HIGH	HIGH	HIGH	MEDIUM
25	HIGH	LOW	LOW	LOW	VERY LOW
26	HIGH	LOW	LOW	MEDIUM	VERY LOW
27	HIGH	LOW	LOW	HIGH	VERY LOW
28	HIGH	LOW	HIGH	LOW	LOW
29	HIGH	LOW	HIGH	MEDIUM	LOW
30	HIGH	LOW	HIGH	HIGH	VERY LOW
31	HIGH	HIGH	LOW	LOW	LOW
32	HIGH	HIGH	LOW	MEDIUM	LOW
33	HIGH	HIGH	LOW	HIGH	LOW
34	HIGH	HIGH	HIGH	LOW	LOW
35	HIGH	HIGH	HIGH	MEDIUM	VERY LOW
36	HIGH	HIGH	HIGH	HIGH	VERY LOW

- **Antecedent 1:** Probability of PU Present (Prob. of PU Pres.) from 1st controller
- **Antecedent 2:** Waiting Time (W. T.)
- **Antecedent 3:** Secondary User Power (SU P.
- **Antecedent 4:** Percentage Ratio of Spectral Utilization (% Spec. UT.)

Generally, the SU with the highest W.T., highest power and lowest % Spec. UT. can be chosen to access spectrum after checking the Prob. of PU Pres. where it should be low. In our system, we combine the above four descriptors to find the best solutions to assign spectrum opportunistically. The main purpose of the OSA scheme is using the spectrum efficiently when different users perceive different available spectrum band.

The novel rule-based decision-making system is presented in table II. Four input parameters of second controller that are considered for the selection of the possibility of allocating (Poss. of Allo. Ch.) idle spectrum to a SU are: (i) the (Pro. of PU Pre.) that fed from the output of first controller; (ii) W.T.; (iii) SU P.; and (iv) % Spec. UT. . The input parameters are first fuzzified from measurable values to fuzzy linguistic variables by using input MBFs. The fuzzy values are then fed into a rule base consisting of IF THEN clauses that represent the mappings between the inputs and outputs of the decision making. The output from the fuzzy reasoning is next mapped to real-world data (in this work, Poss. of Allo. Ch.) by using output MBFs. For simplicity we have used triangular input and output membership functions MBFs, which are commonly used as a baseline approach. Two of the input parameters (the W.T. and SU P.) are assigned using two input membership functions: low and high. On the other hand, the requirement for Pro. of PU Pre. and the percentage ratio of spectral utilization of SU from overall available spectrum are assigned three input membership functions: low, medium or high. The output is the estimation of percentage possibility to allocate idle channel to a SU. The proposed fuzzy decision-making system has several benefits. There are no unexpected outcomes from the decision-making system, since all the possible outputs are determined beforehand when the rules are developed. Also note that it is a one-shot method and does not iterate, thus it operates very fast.

While the baseline decision making system could be implemented with simple IF THEN ELSE rules without FL, the true benefits of using fuzzy decision making come from the flexibility to further tune the system as described above.

3. Simulation Model

Three different signal's transmitters CPFSK, 8QAM and 8FSK are simulated as shown in Fig. (1). These signals are passed through Rayleigh Fading channels. The output of the channels is fed to nine spatially spaced SU node detectors to determine the power of the inputs. The nine detectors are divided into three groups, where each group consists of three detectors focused only on one PU at a time as in Fig.(2). This cooperative detection of three SUs is done to overcome the hidden node problem that occurs when there is an obstacle in front of one or more SU(s) that cause an error in the detection. These three different power information coming from the three SUs detectors are fed to the first controller i.e. first level of HFS as three input parameters (low, medium, high) power. This enable us to be able to take the final decision in fusion centre one about the existence of PU. This happened for PU1 (CPFSK transmitter) i.e. estimate the (Pro. PU Pre.) in first level of first HFS. Also same things happened in second and third branch for 8QAM and 8FSK signals respectively but by using second and third group of other six SUs. In this stage CSS has been done. Now return to the first branch and to complete the OSA process, this information i.e. (Pro. PU Pre.) is fed to the second controller with three other parameters (W.T., SU P., % Spec. UT.) that related to the SUs to decide the possibility of allocating the idle spectrum (if available) to one of these three SUs that already contributed in the detection. Second and third branch also decide which SU has a high possibility to occupy the idle channel(s) of PU2 (QAM) and PU3 (8FSK) respectively.

A. *Hopping System (HS) Module*

The benefit of adding proposed HS before FLS will become clear when the PUs and/or SUs are in mobility case or there is an obstacle between the PU and the SUs that cause problem in detection. So using the nine detectors to sequentially detect the presence of one mobile PU in steps will increase the probability of detection. Where each three SUs, collect different information about one PU because they are spatially spaced around the PU and send it to the fusion centre (FC) to estimate the probability of PU present or not i.e. CSS. Then it feds with the other three antecedents to second FLS to estimate the possibility of which SU can occupy the spectrum i.e. OSA as in Fig. (3), this done in-

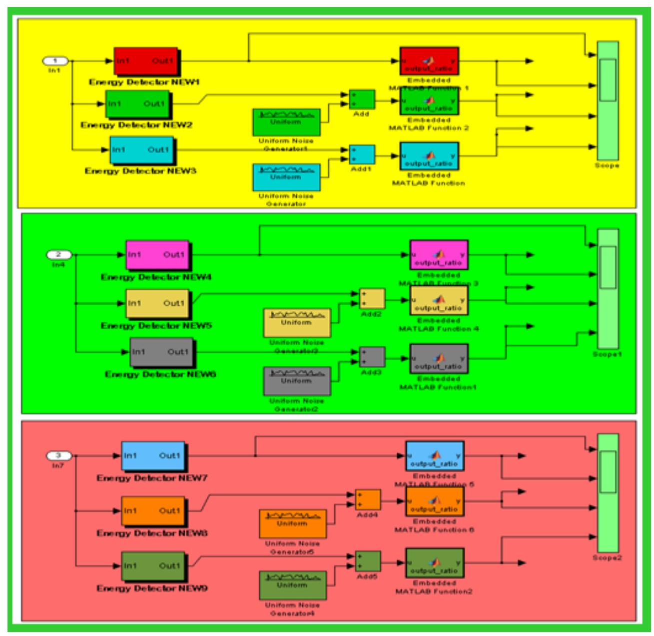
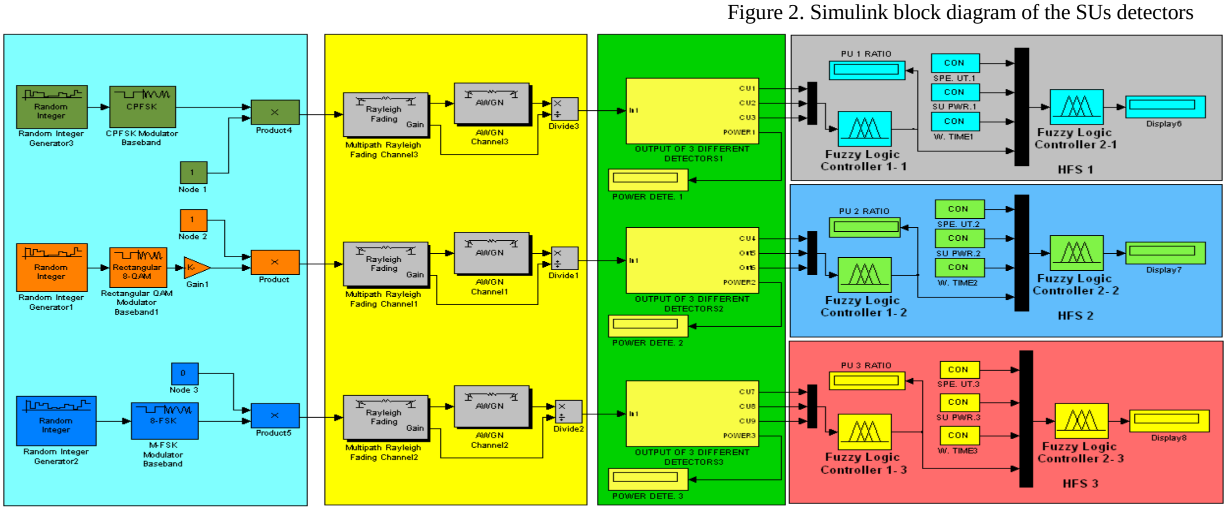


Figure 2. Simulink block diagram of the SUs detectors



Figuer 1. Simulink block diagram for the system

first step of the full period that consists of 9 steps. In second step two of those SUs that already contribute in first step will remain in sensing process and a new SU will assist them in this new step and so on. So in every step, three SUs will cooperate to verify CSS and send their information to second FLS to complete the OSA process. For more reliability we can wait till the ninth step to complete its check i.e. all the nine SUs go through checking this selected PU. But if there is any problem in time delay and the decision is to be taken fast, we can stop the hopping sequence and getting the results in any step.

Example of sensing using HS module:

In first step: If **SU1, SU2 and SU3** start the sequence and chosen to sense **PU1** band;

SU4, SU5 and SU6 are chosen to sense **PU2** band, and

SU7, SU8 and SU9 are chosen to sense **PU3** band

Then the decisions were taken in first controller (CSS) and sent to second controller (second FLS) to estimate the OSA for one of the three SUs that contribute in detection process.

Now if we need to make the two decisions (CSS and OSA) more accurate, we must continuo the second step i.e. **SU2, SU3 and SU4** start sensing **PU1** band,

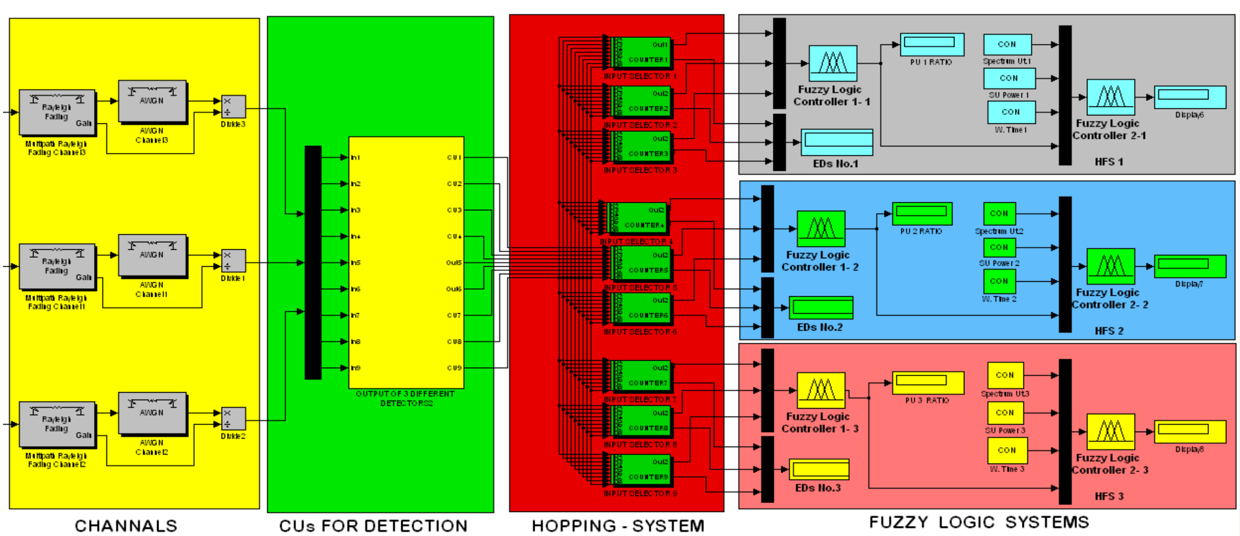
SU5, SU6 and SU7 start sensing **PU2** band,

SU8, SU9 and SU1 start sensing **PU3** band,

The decision also taken and sent to second controller,

And so on as in table III. Fig (4) illustrate the benefit of HS module where PU1 start moving from point (P1) to point (P2) so it become close to SU3, SU4 and SU5 and far from SU1 and SU2. From this example we can visualise how much the detection error will become if we use stationary SUs and depends only on the decision of SU1, SU2 and SU3.

At the beginning and before PU1 start moving, the probability of detection P_d is high because two SUs (SU1 and SU2) out of three detected the presence of PU1. But after PU1 reaching (P2), the P_d will be low because two SUs (SU1 and SU2) out of three couldn't be able to detect the presence of PU1. The same things can happened if the SUs also are in mobility state.



Figuer 3. Hopping System Module

TABLE III. THE HOPPING SEQUENCE PROCEDURE FOR SUs WITH PUs BANDS

Band Checking No.	**SU Number (1-9)**									
	1st step	*2nd step*	*3rd step*	*4th step*	*5th step*	*6th step*	*7th step*	*8th step*	*9th step*	*10th step*
PU1 Band	1	2	3	4	5	6	7	8	9	**1**
	2	3	4	5	6	7	8	9	1	**2**
	3	4	5	6	7	8	9	1	2	**3**
PU2 Band	4	5	6	7	8	9	1	2	3	**4**
	5	6	7	8	9	1	2	3	4	**5**
	6	7	8	9	1	2	3	4	5	**6**
PU3 Band	7	8	9	1	2	3	4	5	6	**7**
	8	9	1	2	3	4	5	6	7	**8**
	9	1	2	3	4	5	6	7	8	**9**

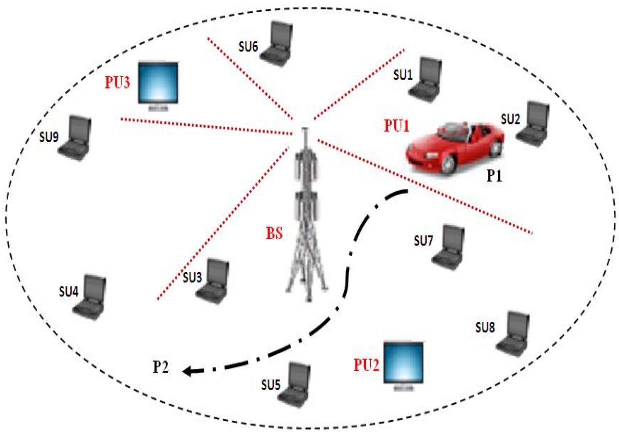


Figure 4. The movement of PU1 among SUs

So, design a stationary detectors while there are mobile PUs will give less probability of detection (Pd). If anyone thinking of increasing the number of stationary detectors to achieve better Pd without using HS, then this will cause an expense of design complexity and more costly.

4. Results and Discussion

The results of the proposed scheme are obtained with and without HS module which are discussed below:

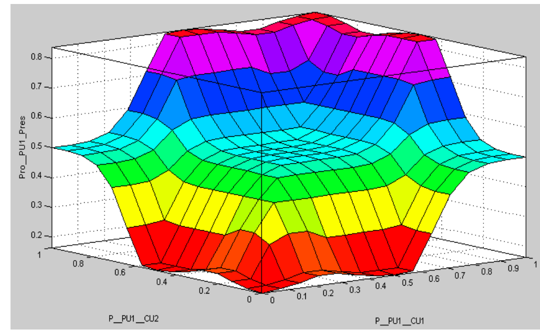
A. Results Without HS module

The decision surface (D.S.) for FLS1 (CSS) is shown in Fig.(5) where the Pro. PU Pre. become high when the power of PU1 measured by at least two CUs (CU1 and CU2) exceed the threshold value of 50%.

Fig.(6) to Fig.(11) shows the decision surface for FLS2 (OSA) i.e. the output of second controller (Poss. of Allo. Ch.) with other parameters. Where the Pro. PU Pre. v.s. W.T., SU POW. and Spec. Ut. in Fig.(6) to Fig.(8) respectively. We can see that the output (Poss. of Ch. Allo.) is very low (under 30%) when the Pro. PU Pre. is high (above 80%) regardless the value of W.T., SU POW. and Spec. Ut.. While if the Pro. PU Pre. is very low (less than 20%) i.e. the channel is idle then:

1) *Form Fig.(6) if the W. T. is less than 65% from the overall waiting time of other CUs, then the output (Poss. of Ch. Allo.) is approximately constant and equal to 60%,* and it is increasing exponentially to become 75% after 85% of W. T. going up to 90% at 100% W. T..

2) From Fig.(7) the output (Poss. of Ch. Allo.) is approximately constant and equal to 65% when SU POW. is less than 40% and increasing to become 75% at 100% SU POW.



Figuer 5. D.S. for FLS1: Pro. PU Pre. with power values for two CUs

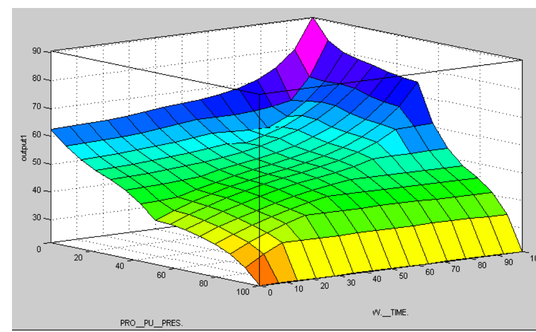


Figure 6. D.S. for FLS2: Poss. of Ch. Allo. With Pro. PU Pre. and W.T.

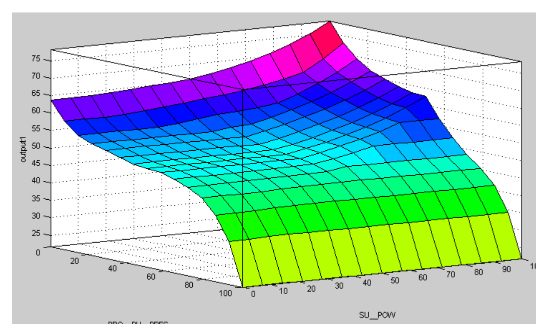


Figure 7. D.S. for FLS2: Poss. of Ch. Allo. With Pro. PU Pre. and SU POW.

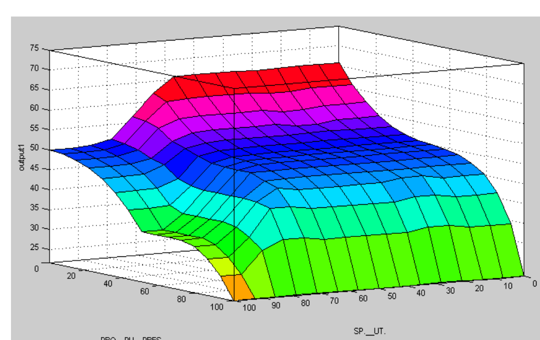


Figure 8. D.S. for FLS2: Poss. of Ch. Allo. With Pro. PU Pre. and Spec. Ut.

3) From Fig.(8) the output (Poss. of Ch. Allo.) is approximately constant and equal to 50% when the CU need to occupy about 80% to 100% from the overall available spectrum and increase to become 65% at SP. UT. less than 60%.

Fig.(9) shows the variation in the (Poss. of Ch. Allo.) with other two parameters (Spec. Ut. and W.T.). Where the output is very low (near to zero) when the (SP. Ut.) is very high (above 95%) and W.T. is very low (less than 10%). Then the output is increasing when these two parameters changing their states.

Result shown in Fig.(10) nearly same to Fig.(9) but the difference is that the output is low (less than 38%) when the SP. Ut. is high (above 90%) regardless the value of SU POW. then also changed when the parameters are changed. The last D.S. Fig.(11) shows that the output (Poss. of Ch. Allo.) is start increasing from zero with increasing both other parameters (W.T. , SU POW.).

Table IV illustrate the overall percentage of Pro. PU Pre. of first FLS (CSS) for many states of input power values that determined by three CU detectors after applying equations (7) and (8) [12]. While this determined power compared with a threshold level to convert it to a percentage probability of present (existence) from 0 to 1. It can be explained as; IF (Pro. PU Pres. at SUn) IS (x1) AND (Pro. PU Pres. at SUn+1) IS (x2) AND (Pro. PU Pres. at SUn+2) IS (x3) THEN the (Overall % Pro. of PU Pres.) IS (y). The value (18.9 %) represent the overall percentage probability of PU1 i.e (CPFSK) present in case when SU1 with Pro. of (0.211), SU2 with Prob. of (0.041) and SU3 with Prob. of (0.150) nodes detected PU1 and using FL determination. The same explanation for the values (55.3 % and 82.6 %) but for PU2 detected by (SU4, SU5 and SU6) and PU3 detected by (SU7, SU8 and SU9) respectively.

Also we can see that the (Overall % Pro. of PU Pres.) increases with increasing the value of any two inputs. While this determined power compared with a threshold level to convert it to a percentage probability of present (existence) from 0 to 1as in Fig.(5). This overall percentage probability will be fed with other three inputs to second FLS as in table V. Nine CUs with four parameters are used to determine the (Poss. of Ch. Allo.) after applying equations (9) and (10).

TABLE IV. THE OVERALL PERCENTAGE PROBABILITY OF FIRST FLS FOR DIFFERENT POWER VALUES DETERMINED AT CUS

Value of (n)	PU No.	Pro. PU Pres. at SUn	Pro. PU Pres. at SUn+1	Pro. PU Pres. at SUn+2	Overall % Pro. of PU Pres.
1	1	0.211	0.041	0.150	**18.9**
4	2	0.536	0.259	0.837	**55.3**
7	3	0.922	0.886	0.898	**82.6**

It can be explained as; IF (Overall % Pro. of PU Pres.) of any PU (from 1 to 9) determined by a group of three SUs

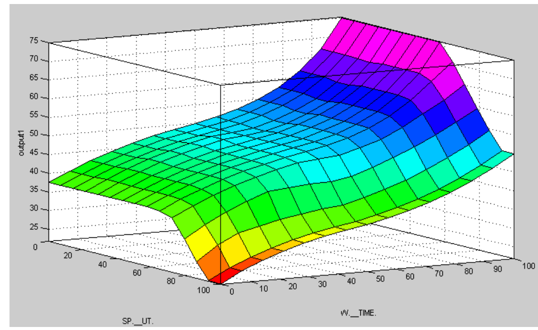


Figure 9. D.S. for FLS2: Poss. of Ch. Allo. With Spec. Ut. and W.T.

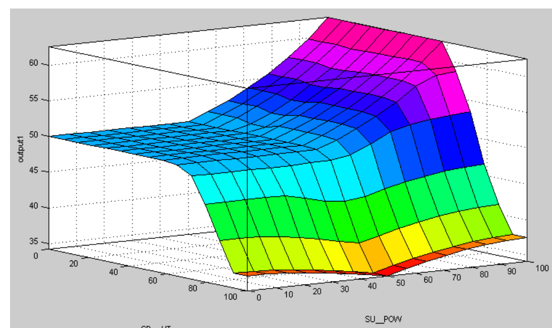


Figure 10. D.S. for FLS2: Poss. of Ch. Allo. With Spec. Ut. and SU POW.

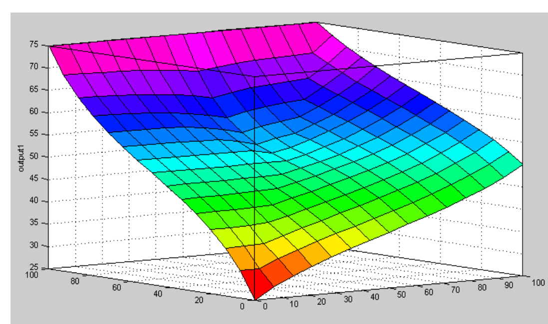


Figure 11. D.S. for FLS2: Poss. of Ch. Allo. With W.T. and SU POW. .

IS (x1) AND the three parameter values i.e. (W. T.), (SU P.) and (SP. UT.) of SUn ARE (x2, x3, x4) THEN (Poss. of Allo. Ch.) for this specific SU IS (y). We can see that the very important parameter in this table i.e. (Overall % Pro. of PU Pres.) comes from the output of 1st FLS. If the value of this parameter increases then the 2nd FLS output i.e. (Poss. of Allo. Ch.) decreases regardless of the other three inputs. But if this value is less than a threshold value of about 50 % then the value of (Poss. of Allo. Ch.) will be depends on the other two parameters, as it increases with increasing the values of (W.T.) and (PU P.) while decreasing the value of (% SU Spectrum UT.) and vies versa. This last parameter means that how much spectrum does the SU needs to occupy from the overall PU band. So if the value is high, the (Poss. of Allo. Ch.) will be low and vies versa. Also from table IV we can identify that SU1 with parameter values (93.1, 88.6 and 14.6) can occupy channel one, because of its high value of Poss. of Allo. Ch. with (72.2) than other two SUs i.e. SU2 with (63.3) and SU3 with (51.4).

TABLE V. THE POSS. OF CH. ALLO. OF SECOND FLS FOR NINE SU AND FOUR INPUT PARAMETERS

SU No.	Overall % Pro. of PU Pres.	% SU_n Parameters			% Poss. of Allo. Ch.
		W.T.	*SU P.*	*SP. UT.*	
1	18.9	93.1	88.6	14.6	**72.2**
2		37.7	93.2	30.0	**63.3**
3		62.3	32.6	90.0	**51.4**
4	55.3	45.4	47.7	39.2	**48.8**
5		90.0	82.6	20.8	**63.5**
6		23.8	31.1	88.5	**30.4**
7	82.6	10.0	94.7	90.0	**24.0**
8		40.8	76.5	57.7	**43.4**
9		91.5	25.0	33.1	**44.5**

For channel two there is some possibility for SU5 to occupy it than SU4 and SU6. Channel three is not idle, that mean PU3 is presents and no any chance for SU7, SU8 and SU9 to occupy it. Because of the very high value of (Overall % Pro. of PU Pres.) and very low value of (Poss. of Allo. Ch.) in this case.

$$C^l_{avg3} = \frac{\sum_{i=1}^{3} w_i^l C^i}{\sum_{i=1}^{3} w_i^l} \dots\dots\dots (7)$$

There are 27 rules in FLS1. Where L = 1,2,…….27 and c^l_{avg3} is defined as in eq (7) in which c^i is the centroid of the i^{th} consequence set (i = 1,2,3 ; L = 1,2, …….27) and w_i^l is the number of experts choosing linguistic label (i) for the consequence of rule l. For every input (x1 ,x2, x3) the output y_{FLS1}(x1,x2,x3) of the designed system is computed as

$$y_{FLS1} = (x1; x2; x3) = \frac{\sum_{l=1}^{27} \mu F_1^l(x1)\mu F_2^l(x2)\mu F_3^l(x3) C^l_{avg3}}{\sum_{l=1}^{27} \mu F_1^l(x1)\mu F_2^l(x2)\mu F_3^l(x3)} \dots\dots\dots (8)$$

We can apply same above equations to second FLS but changing the number of parameters to become: (L = 1,2,3,…….,36) and (i = 1,2,3,4,5) as in equations (9) and (10) to get the values in table V

$$C^l_{avg5} = \frac{\sum_{i=1}^{5} w_i^l C^i}{\sum_{i=1}^{5} w_i^l} \dots\dots\dots (9)$$

$$y_{FLS2} = (x1; x2; x3; x4) = \frac{\sum_{l=1}^{36} \mu F_1^l(x1)\mu F_2^l(x2)\mu F_3^l(x3)\mu F_4^l(x4) C^l_{avg5}}{\sum_{l=1}^{36} \mu F_1^l(x1)\mu F_2^l(x2)\mu F_3^l(x3)\mu F_4^l(x4)} \dots\dots\dots (10)$$

B. Results With HS Module

The Probability of Detection (P_d) for the three transmitted signal (CPFSK, 8QAM and 8FSK) with SNR are illustrated in table VI and Figs. (12,13 and 14) respectively. The plane line denote the P_d when sensing the band of a mobile PU without using HS module while the signed line represent the P_d when HS module added to the system. So the enhancement in CSS are very clear in these three cases when using HS module and the P_d of the mobile PU is become higher. This enhancement is about 0.08, 0.09 and 0.14 at SNR (-5dB) for CPFSK, 8QAM and 8FSK respectively. So from the results it is concluded that P_d increases with the introduction of HS module.

TABLE VI. THE PROBABILITY OF DETECTION FOR THE THREE PUS WITH & WITHOUT HOPPING SESQUENCE VS. SNR

SNR (dB)	% P_d of PU1		% P_d of PU2		% P_d of PU3	
	Without HS	*With HS*	*Without HS*	*With HS*	*Without HS*	*With HS*
-20	8	10	6	8	15	15
-15	30	35	18	28	25	33
-10	60	70	57	68	59	65
-5	82	90	80	89	78	94
0	92	98	90	96	93	98
5	95	100	95	98	97	100
10	98	100	95	100	99	100
15	100	100	98	100	100	100
20	100	100	100	100	100	100

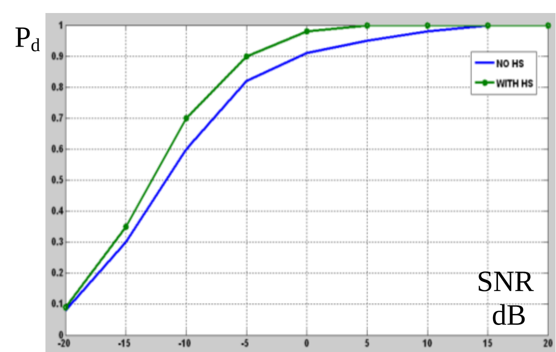


Figure 12. P_d for CPFSK Signal with and without HS vs. SNR

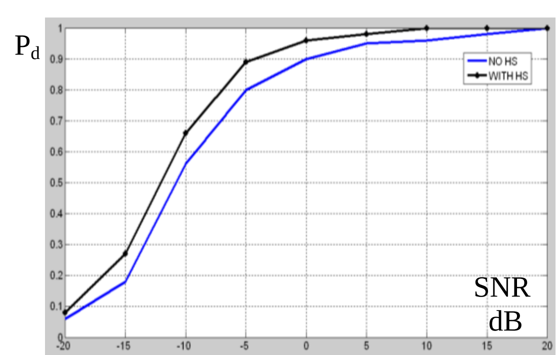


Figure 13. Pd for 8QAM Signal with and without HS vs. SNR

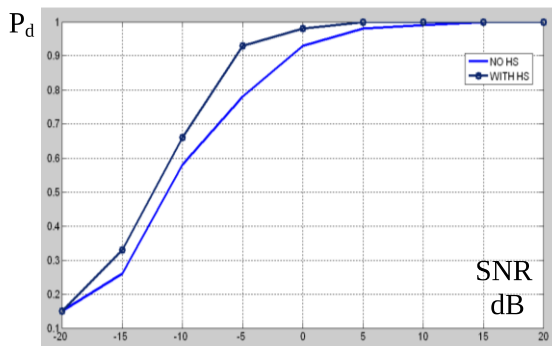


Figure 14. Pd for 8FSK Signal with and without HS vs. SNR

5. Conclusions

In this paper we have proposed a novel concept of using two levels Hierarchical Fuzzy Systems (HFS) based cooperative spectrum sensing (CSS) in level 1 and opportunistic spectrum access (OSA) techniques in level 2. Three separate groups of Hierarchical Fuzzy Systems (HFS) were designed to estimate the probability of presence for three primary users (PUs) in first controller (level 1). Which is dependent on 27 rule based FLS with three antecedents. Each three SUs collect a different information about one PU and send it to the fusion center to estimate the probability of PU present. Then estimate the percentage ratio of allocating idle channels to three out of nine CUs in second controller (level 2) depends on 36 rule based FLS with four antecedents. One is already fed from first controller and other three are very important parameters, they are: (i) waiting time (W. T.) of every SUs that spent to occupy the idle channel, (ii) Available power for every SU (SU. POW.), (iii) The percentage ratio of spectral utilization of SU from overall available spectrum (%SP. UT.). The results indicate that FL can be used in CSS to provide additional flexibility in decision making and in OSA to allow the CU with highest possibility of spectrum access to occupy the available band. Also hopping system (HS) modules were proposed here when PU(s) and /or SU(s) are in mobility state and the results shows an enhancement in probability of detection of PU.

Acknowledgment

The authors would like to express their appreciation to the Ministry of Higher Education and Scientific Research in Iraq and Jamia Millia Islamia in India for supporting this work.

References

[1] J. Mitola III and G. Q. M., Jr., "Cognitive radio: making software radios more personal", IEEE Personal Communications Magazine, Vol. 6, issue 4, 13-18, Aug. 1999.

[2] S. Haykin, "Cognitive Radio: Brain-empowered Wireless Communications", IEEE Journal on Selected Areas of Communications, Vol. 23, issue 2, 201-220, Feb. 2005.

[3] Q. Zhao and B. M. Sadler, "A survey of dynamic spectrum access", IEEE Signal Processing Magazine, Vol. 24, No. 3, 79–89, 2007.

[4] Ekram H., Dusit N. Zhu H., "Dynamic Spectrum Access and Management in Cognitive Radio Networks", Cambridge University Press, 2009.

[5] Yipeng Liu and Qun Wan, "Enhanced Compressive Wideband Frequency Spectrum Sensing for Dynamic Spectrum Access" EURASIP Journal on Advances in Signal Processing , Vol. 3, 2012.

[6] M. J, Y. W T, L. H S, et al. "Collaborative spectrum sensing from sparse observation in cognitive radio networks", IEEE J. Sel Areas Commun, , Vol. 29, 327–337, 2011.

[7] Ammar Abdul-Hamed Khader, Ahmed M. Husein Shabani and Mirza Tariq Beg, "Spectrum Sensing of Cognitive Radio: A Survey", European Journal of Scientific Research, Vol. 100, No. 3, May, 2013.

[8] Waqas Khalid, Heejung Yu, "Optimal sensing performance for cooperative and non-cooperative cognitive radio network", International Journal of Distributed Sensor Networks, Nov. 30, 2017.

[9] Zhang Ping, Liu Yang, Feng Zhiyong, Zhang Qixun, Li Qian & Xu Ding, "Intelligent and efficient development of wireless networks: A review of cognitive radio networks", Chines Science Bulletin October, Vol.57, No.28-29, 3662- 3676, 2012.

[10] Debjani Mitra and Rupanwita Das Mahapatra, "FIS Based Cognitive Radio Scheduling", IEEE International conference on Fuzzy Systems, Jul., 2013.

[11] S-F Yang and J-S Wu, "A spectrum sharing method based on fuzzy logic in IEEE 802.22 WRAN", Proc. IEEE Int. Conf. Wireless Comm. and Signal Processing (WCSP) , 1-5, 2010.

[12] T. Le. Hong-Sam, D. Ly Hung, and Q. Liang, "Opportunistic spectrum access using fuzzy logic for cognitive radio networks", Int. J. Wireless Information Networks, Vol. 18, No. 3, 171–178, Sep., 2011.

[13] F. Koroupi, H. Salehinejad And S. Talebi, "Spectrum Assignment In Cognitive Radio Networks Using Fuzzy Logic Empowered Ants", Iranian Journal of Fuzzy Systems Vol. 10, No. 6, 1-19, 2013.

[14] N. B., M. Zorzi, "Fuzzy Logic for Cross-layer Optimization in Cognitive Radio Networks", in Proceedings of 4th IEEE Consumer Communications and Networking Conference, 11-13 Jan., Las Vegas, USA, 2007.

[15] Hazem S. Shatila: Adaptive Radio Resource Management in Cognitive Radio Communications using Fuzzy Reasoning. Ph.D. thesis, Virginia, 2012.

[16] M. Matinmikko, T. Rauma, M. Mustonen, "Application of Fuzzy Logic to Cognitive Radio System" IEICE Transaction on Communication Vol. E92-B, No.12 Dec. 2009.

[17] Tallataf Rasheed, Adnan Rashdi, Ahmad Naeem Akhtar, "Reliability Factors Based Fuzzy Logic Scheme for Spectrum Sensing", International Journal of Information and Communication Engineering Vol. 12, No. 2, 2018.

[18] Raju, G. V. S. and J. Z., "Adaptive Hierarchical Fuzzy Controller", IEEE Transactions on System Man and Cybernetics, Vol. 23, No. 4, 973-980, 1993.

[19] Ammar Abdul-Hamed Khader, Ahmed Hameed Reja, Arkan Ahmed Hussein, M.T.Beg, Mainuddin, "Cooperative Spectrm Sensing Impovment Based on Fuzzy Logic System", Procedia Computer Science, Vol. 58, 34-41, 2015.

[20] Q. Zhao, S. Geirhofer, L. Tong and Brian M. Sadler, "Opportunistic spectrum access via periodic channel sensing", IEEE Transa. On Signal Processing, Vol. 56, No. 2, 785-796, Feb. 2008.

[21] Q. Zhao, "Spectrum opportunity and interference constraint in opportunistic spectrum access", Proc. IEEE International Conference on Speech And Signal Processing (ICASSAP), Vol. 3, Apr., 605-609, 2007.

[22] H. Sam T. Le H. D. Ly Qilian Liang, "Opportunistic Spectrum Access Using Fuzzy Logic for Cognitive Radio Networks", Int. J. Wireless Inf Networks, Vol. 18, 171–178, 2011.

[23] Prabhjot Kaur: Medium Access Control Design And Analysis For Dynamic Spectrum Access In Cognitive Radio Networks, Ph.D. thesis, 2012.

[24] K. R , D. Nesa Kumar. C and Prakash, "A Fuzzy Logic System for Opportunistic Spectrum Access using Cognitive Radio", International Journal of Computer Science Issues, Vol. 10, No. 1, No. 1, Jan. 2013.

[25] R. K., Dr. C. Chandrasekar, "Comparing Spectrum Utilization using Fuzzy Logic System for Heterogeneous Wireless Networks via Cognitive Radio", International Journal of Scientific & Engineering Research, Vol. 3, No. 7, Jul. 2012.

[26] Yee Ming Chen, Pei-San Tsai, "Opportunistic Spectrum Access Decision Operation in Cognitive RadioFemtocell Networks using Fuzzy Logic System", International Journal of Computational Intelligence and Information Security, March Vol. 3, No. 3, 2012.

[27] Ila Sharma, "A Novel Approach for Spectrum Access Using Fuzzy Logic in Cognitive Radio", Int. J. Information Technology and Computer Science, Vol. 8, 1-9, 2012.

[28] Partha Pratim Bhattacharya, Subhajit Chatterjee, "A New Fuzzy Logic Rule Based Power Management Technique for Cognitive Radio", International Journal of Computer Science and Mobile Computing, Vol. 2, No. 2, Feb., 6 – 11, 2013.

[29] E. MoeenT., B. Abolhassani, "A Fuzzy Secure Spectrum Sensing (F3S) Scheme for Cognitive Radios in Adversarial Environment", International Conference on Computer Communication and Management Proc. of CSIT vol.5, IACSIT Press, Singapore, 2011.

Dr. Ammar Abdul-Hamed Khader was born in Mosul / Iraq on November, 1971. He received the B.Sc degree in Electrical Engineering/Electronics and Communication (ECE) Department from University of Mosul/ Iraq in 1993, and M.Sc. in Communication Engineering from University of Technology / Baghdad / Iraq in 2004. His Ph.D. was received from Jamia Millia Islamia (JMI), New Delhi / India in Radio Resources Management in Wireless Networks in 2015. He is an academic staff in the department of Computer Engg. in Mosul University/ Iraq since 2004. He is the author of 19 papers in valuable, impact factor and International Journals and proceedings of conferences. He serves as reviewer for several papers. His research interests in Wireless Communication, Spread Spectrum Systems, Cognitive Radio Systems, Data Communication and Signals Detection Systems.

Prof. Dr. Jassim M. Abdul-Jabbar was born in Basrah, Iraq, on July 25, 1958. He received the B. Sc. degree in Electrical Engineering (1979), the M. Sc. degree in Electrical Engineering (1983), and the Ph.D. degree in ECE (1997); all from Department of Electrical Engineering, University of Basrah, Basrah, Iraq. He was the Head of Dept. of Computer Engineering (CE), University of Basrah (1998-2002), Dean Asst. – College of Engineering, University of Basrah (2003-2004) and Head of Dept. of CE, University of Mosul (2011-2018). Since 2018, he is the chairman of the central committee for scientific promotions at the University of Mosul. He is currently a Professor of Signal and Image processing, Department of CE, University of Mosul, Mosul, Iraq. His research interests include analogue and digital signal processing, image processing, filter banks and wavelets, FPGA-based system design & realization, wavelet and wavenet techniques for system control and identification, computer network application improvements, cognitive transceivers, biomedical information and engineering. He is the supervisor of more than 50 M. Sc., and Ph.D. theses in Electrical Engineering, Computer Engineering, Computer science, Mathematics and physics, in the University of Basrah and then in the University of Mosul. He is the author of more than 72 papers.

Dr. Rabee M. Hagem received the B.Sc. degree in Electronics and Communication engineering, in 1998 and the M.Sc. degree in 2001 from University of Mosul, Mosul, Iraq. He received his Ph.D. degree from Griffith University/Queensland/Australia in underwater optical wireless communication for real time swimmers feedback in 2014. He is a member of the Centre for Wireless Monitoring and Applications with Griffith University. He has been a Lecturer with the Computer Engineering Department, Mosul University, since 2003 till now. He was a R&D Engineer for North Mosul Electricity Distribution Company in 2001 and 2002 and as a QA/QC Engineer for ABB Company for extension of Mosul 400 Kv substation project in 2007. His current research interests include underwater optical wireless communication, design and implementation of smart sensors, embedded systems for athletes monitoring, and sport data analysis.

Prof. Dr. Mainuddin received Bachelor's degree in Electronics and Communication Engineering (ECE) from Jamia Millia Islamia (JMI) in 1994. He received M.E. degree from the Department of ECE, Delhi College of Engineering in 2003, and the Ph.D. in 2008 from JMI, New Delhi. He is presently working as a Professor at the department of ECE, JMI, New Delhi. He worked as a Senior Research Scientist at Laser Science and Technology Centre, DRDO, New Delhi for more than 16 years. He has published 27 research papers in archival journals with high impact factor like IEEE Transactions, Optical Research, Optics & Laser Technology, etc. He has authored a book and seven book chapters published by Springer, Cambridge University Press and Nova Publishers. In addition he has presented 28 papers in International refereed conferences and 36 national conferences/ symposiums. He serves as reviewer (on invitation from Editor) for IEEE Transaction on Instrumentation and Measurement, Instrumentation Science and Technology and Optics and Laser Technology.

Prof. Dr. Mirza Tariq Beg received his B.Tech. degree in Electronics and Communication Engineering (ECE) in 1985 from AMU University, Aligarh, India, and Master of Engineering in 1987 from Delhi University, Delhi, India, and Ph.D. in 2003 from Jamia Millia Islamia, New Delhi. He was the Head of Department of ECE (2012-2014). Since 2014 till now he is a Director of the Centre for Distance & Open Learning Jamia Millia Islamia, New Delhi He has more than 40 publications in journals and conferences of repute. His research area includes Wireless Communication, Electronic Instrumentation, Real Time Systems, Low Power Circuit Design, Data Communication, Wireless Networks, Wireless Sensor Networks, Wireless Security, Spread Spectrum System, Mobile Communications. He is the supervisor of more than 10 M. Sc., and Ph.D. theses in Electronics and Communication Engineering