International Journal of Engineering & Technology, 7 (2.33) (2018) 266-272

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Design of fuzzy logic system for cognitive radio networks for efficient spectrum decision and channel assignment

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Abstract

Wireless sensor networks (WSNs) are becoming highly preferable for various day to day applications. Cognitive radio (CR) is a paradigm that can deploy IPV6, which has built-in auto configuration features along with large 128-bit address space for efficient spectrum allocation by considering all possible QOS parameters. An efficient spectrum decision has been developed based on fuzzy for secondary users channel assignment. The parameter such as Signal strength, node velocity and distance between PU and SU for unused available BW IPV6 header has been identified for information such as text, voice or video to be forwarded by the Secondary users with efficient spectrum allocation. The spectrum decision and channel assignment for secondary users has been simulated to obtain satisfactory results

Keywords: *Wireless sensor network; Cognitive radio; Fuzzy logic; Spectrum management.*

1. Introduction

Wireless communication has been developed in the area of communications over the period of years. With the incredible development of wireless systems and services, the accessibility of high quality wireless spectrum has become severely limited. This has led to a common belief that the spectrum is limited and it is difficult to find spectrum for new applications. However, actual measurements carried out in various countries show that most of the radio frequency spectrum is inefficiently utilized mostly in the range of 5%-50% [1]. Therefore, the spectrum scarcity was not considered as major issue, instead of using the spectrum inefficiently but the inefficient spectrum usage.

The opportunistic usuage of spectrum resources has been allowed by CR to avoid the under utilization of spectrum. The best available spectrum band that satisifies the SU's QOS requirements has been referred as spectrum decision by not interferring the licensed or PU's. The available spectrum bands has been identified for spectrum sensing and these bands for opportunistic user has been selected for Spectrum decision making process [2]. Spectrum Characterization, Spectrum Selection and CR Reconfiguration [4] are the three main process involved for Spectrum decision. Spectrum Characterization defines the required bandwidth for different information types like text, voice and video. Based on traffic patterns, SU's QOS for spectrum band has been assumed properly for Spectrum selection. Finally, the transmission parameters allow communication for the selected band by reconfiguring the CR. The combination of WSN and CRN with opportunistic spectrum access capabilities are referred as Cognitive wireless sensor network.

The requirement has been designed and developed for IPV6 enabled sensor networks to attain its goal. the implementation of an IP stack in the sensor nodes and appropriate inter-working between the IP layer and the link layer. The priority to spectrum decision and suitable channel BW allocation has been proposed to focus on opportunistic spectrum access for SU's by adopting the FLS tool box in MATLAB.

2. Related work

Received signal strength, interference, path loss, wireless link error, link layer delay were the parameters that illustrates the channels has been illustrated in [9]. The channel access for SU has been selected by theses parameters. However, this strategy Offers growth to a multiple-constraint based decision making problems.

Similarly, in [10] the authors has the parameters like mobile and received speed signal strength for SU side to represent the channel availability. the authors constructed a fuzzy logic based decision system to help SUs in doing channel selection by presenting a set of fuzzy rules.

Fuzzy rules are not flexible for SUs to adjust the radio environment varying over time. However, for statistical information about radio environment, changes are desirable for SUs towards spectrum decision.

Further, in [11], the authors suggested a two-state free-busy Markov chains based model to theoretically study the interaction between PUs and SUs. Alternatively, in [12] the authors suggested a hybrid free-busy model, where the length of the state free is fixed and the length of the state busy is exponentially distributed.

In reference paper [13], the authors adopted the hybrid free-busy model to investigate the blocking and dropping probabilities of SUs data transmission. To be called cognitive, the SUs should also have the capacity of learning from the radio environment changes. To provide this ability, Computational Intelligence (CI) based algorithms are applied in spectrum decision strategies.

3. Proposed work

CR-WSN are different from conventional WSN, the conventional MAC protocol for WSN depends basically on the physical layer (PHY). However, carrier sensing is not sufficient for CR-WSN because the nodes need to have complete knowledge about the spectrum availability. Conventional WSNs retransmit packet after a collision but in CR-WSN the nodes need to determine whether the collision is owing to PU or not. If so, then the SU have to leave the channel immediately.

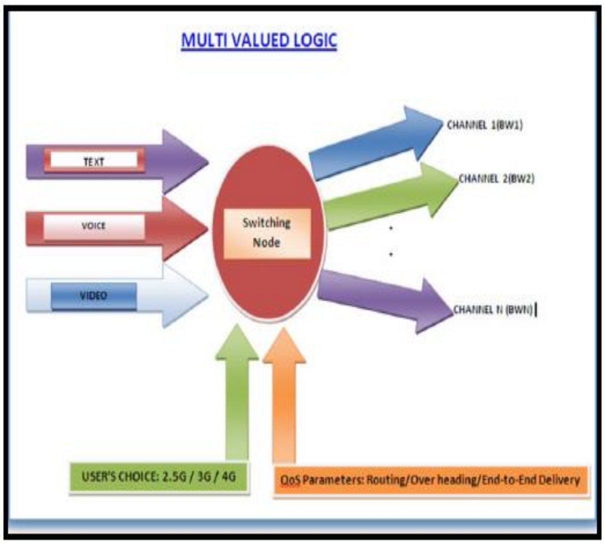


Fig. 1: Channel Band Width Assignment Based on the Types of Services.

In CR networks, the spectrum holes are determined by different sensing techniques that are available to SUs for efficient spectrum utilization. To encounter such requirement, effective spectrum decision and spectrum allocation must be done. the proposed work has been shown in Figure 1, SU is considered as switching node by specifying different QOS parameters and type of information such as text, voice and video are identified based on the IPv6 address bits.

Spectrum allocation for the SU has been chosen depending upon the availability of the existing spectrum band and the type of information being allotted. IPv6 decides the existence of channel. The Spectrum allocation has been done effectively by categorising the channel bandwidth as Low, Medium and High for the allocation of diverse information types available with SU for transmission.

4. Fuzzy logic for spectrum decision based on QOS parameters

In CR-WSN, Based on the presence of SU's, A fuzzy logic based system is proposed for taking decision and utilization of unused spectrum. Fuzzy logic has the capability to handle a multi-valued logic based node which has multiple input and output parameters and capability of taking the decision. The different QOS parameters available for the SU are the signal strength (SS), node velocity and the distance between SU and PU.

In this approach, three parameters are used for accessing spectrum opportunistically out of which the first one being the signal strength of the secondary user which is based on different propagation models. Free path propagation model is considered due to the requirement of less signal strength and QOS degradation exists at the boundary of service cell or area. Second parameter is the SU node velocity which is used to determine the mobility of the SU that can reduce the chance of spectrum access or incorrectly determined unused spectrum. Third is the distance between secondary user (SU) and primary user (PU). If the location of primary user is unknown, then signal to noise ratio is considered as substitute to determine distance. Among the presence of SU's , the user at a closer distance is given priority to access spectrum than other users that are far away from network.

Based on the knowledge of the various input parameters i.e. signal strength, node velocity, distance between SU and PU, the member ship function is used to take decisions for accessing the spectrum. The Gaussian member ship function represents the input parameters that are divided into three levels such as low, medium, high. Fuzzy rules are used to take decision for opportunistic spectrum access. The output membership function of the SU accesses the spectrum that are divided in to five levels such as Very Low, Low, Medium, High, Very High. Based on the results of output membership functions, the unlicensed secondary user with maximum possibility of decision can use the available unused spectrum.

The fuzzy rules are applicable based upon the behaviour of Fuzzy Logic System(FLS) that depends on 'if' and 'then' statements. These fuzzy rules are found out with the formula

Mn = 33 = 27.

Where m represents inputs memberships functions, n represents the total number of inputs.

The consequences of FLS are considered based on various logics defined and shown in below table. For example, if the signal strength of SU is High, node velocity is Less, the distance between SU and PU is Less; then the possibility of the secondary user to access the spectrum or spectrum decision is High. Similarly, for various 27 combinations to access the spectrum are as shown in Table 1.

Table 1: Rules Used for Taking the Decision

S. No	Signal Strength	Velocity	Distance	Decision
1	Low	Low	Low	High
2	Low	Low	medium	Medium
3	Low	Low	high	Low
4	Low	medium	Low	Medium
5	Low	medium	medium	Medium
6	Low	medium	high	Low
7	Low	High	Low	Low
8	Low	High	medium	Low
9	Low	High	high	Very Low
10	Medium	Low	Low	High
11	Medium	Low	medium	Medium
12	Medium	Low	high	Low
13	Medium	medium	Low	Medium
14	Medium	medium	medium	Medium
15	Medium	medium	high	Medium
16	Medium	High	Low	Medium
17	Medium	High	medium	Medium
18	Medium	High	high	Low
19	High	Low	Low	Very High
20	High	Low	medium	High
21	High	Low	high	High
22	High	medium	Low	High
23	High	medium	medium	Medium
24	High	medium	high	Medium
25	High	High	Low	High
26	High	High	medium	Medium
27	High	High	high	Low

Based on fuzzy rules, various possibilities to access the spectrum used by secondary user are decided

5. Hierarchy to generate ipv6 128 address bits

Based on services, the type of network available for SUs are categorized as 2.5G, 3G, 4G. Cognitive radios can be used for LTE and user choice of network can be 4G as shown in figure1. Table 2 depicts the possible levels the FLS should undergo before spectrum decision and channel assignment. Different channel band widths can be available for different type of information's that the user want to transmit i.e. data/text: Low, voice: Medium, video: High

Table 2: Parameters for Channel Allocation

Level 1	4G	3G	2.5G
Level 2	Circuit switching	Message Switching	Packet Switching
Level 3	Datagram	SVC	PVC
Level 4	RIP	OSPF	ISIS
Level 5	RFC 1058	RFC 1723	MDVRP
Level 6	IP	ICMP	IGMP
Level 7	Text	Voice	Video

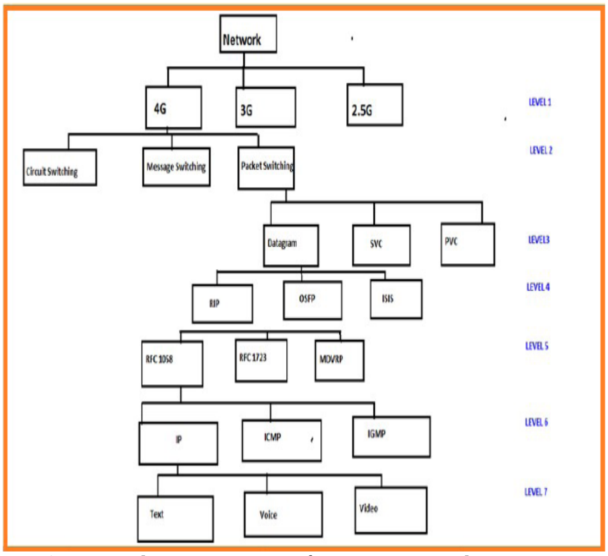


Fig. 2: Levels Representation of Parameters Based on Priority.

In the proposed work, Cognitive Radio Network comprises of secondary users (SUs) and the behaviour of SUs are discussed using Fuzzy Logic System. Let us assume the node to which the SU attached in the network as Level-1, type of network (4G,3G,2.5G) as Level-2, model of data transmission as Level-3, type of connectionless circuit as Level-4, type of routing protocol as Level-5, various RIP version as Level-6, types of protocols as Level-7 and type of service provided by the node as Level-8 respectively.

Based on the priority and knowledge of parameters defined in eight levels as shown in figure 2, the parameters are assigned with multi-level logic that has three logic values such as low, medium and high. Each assigned logic value has16 bit predefined code that generates 128bits for IPv6 address bits. Based on the flow structure shown in figure2 various combinations for allotting the channel BW are obtained. Among the various combinations obtained, the parameters with minimum three combinations are considered for assigning the suitable BW and the types of services used are text, speech and video. If the type of service is text, then the Channel BW (BW1) is allotted, and if the type of service is speech, then the Channel BW (BW2) is allotted. Next if the type of service is video, then the Channel BW (BW3) is allotted and hence effective spectrum allocation is achieved.

6. Performance parameters

6.1. Signal strength

The free space propagation model is considered [4] for determining the signal strength of the secondary user. Frii's free space propagation model equation is given by

$$Pr=PtGtGr\ (\lambda 2)/\ (4\pi d)\ 2L \qquad (1)$$

Where Pt is the transmitted power, Pr is the received power Gt is the transmitter antenna gain, Gr is the receiver antenna gain, d is the Transmitter-Receiver separation and L is the system loss factor depended upon line attenuation, filter losses and antenna losses.

6.2. Node velocity

Node velocity determines the mobility of SU. When the secondary user is moving at a velocity v m/s, from [4] we consider the range 0-10m/s

6.3. Distance

It is the distance between PU and SU [4].

$$rs = 10 \log \left(\frac{P1\ g(R)}{\sigma 1^2}\right) \qquad (2)$$

Where P1 is the transmit power of the primary user and $\sigma 1^2$ is noise power measured at the secondary user.

From (2) the distance R between primary user and the secondary user is found and assuming SNR value in such a way that R lies between 0– 100m.

7. Results

To validate the approach, a wireless sensor cognitive radio network is considered with primary users and secondary users, where the Primary Users [PUs] are placed randomly. Three descriptors are randomly generated for each Secondary User [SU]. The performance of the SU to access the spectrum depend on the QOS parameters. In this paper, based on IEEE 802.15.4 standards, the performance parameter ranges for three descriptors are considered as Signal Strength (SS) in the interval [-100 to -80dbm], Node Velocity in the interval [0-10m/s] and distance between Primary and Secondary User in the interval [0-100m] which are randomly generated.

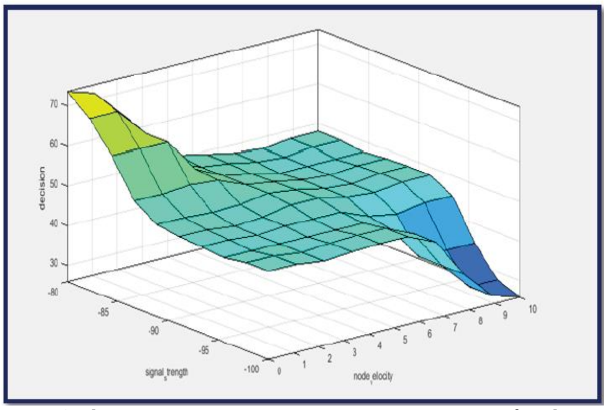


Fig. 3: A) The Opportunistic Spectrum Access Decision Surface by Considering a Distance between SU & PU.

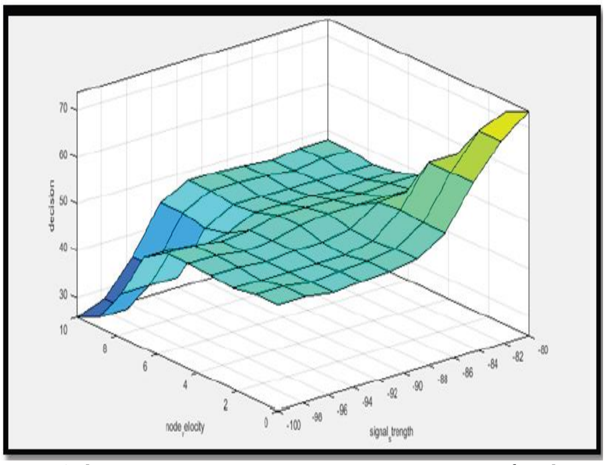


Fig. 3: B) the Opportunistic Spectrum Access Decision Surface by Considering a Distance between SU & PU.

Figure [3] (a), (b) shows the relation between signal strength, node velocity and possibility of taking decision to access the spectrum by considering a distance between SU and PU. The graph depicts that for the signal strength ranging from -100 to -96dbm, the node velocity ranges from 9-10m/s the possibility of decision to access spectrum is very low. Table 3 shows possibility of opportunistic spectrum access with respect to signal strength and node velocity

Table 3: Possible Opportunistic Spectrum Access and Spectrum Decision

S. No	Signal strength (dbm)	Node velocity (m/s)	Possibility to access spectrum (%)	Spectrum Decision
1	-100 to -96	9 -10	1-10	Very low
2	-96 to -94	6 - 8	11-49	Low
3	-100 to -90 -90 to -80	0 - 5 5 - 10	50	Medium
4	-85 to -82	2 - 3	51-90	High
5	-82 to -80	0 - 2	91-100	Very high

Similarly, all cases are observed as shown in the table3.

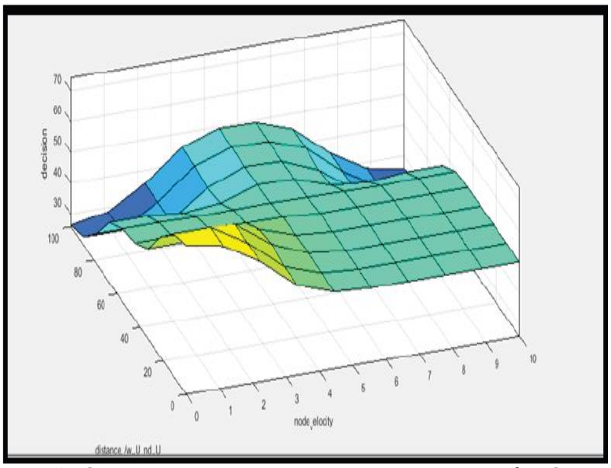


Fig. 4 A) The Opportunistic Spectrum Access Decision Surface by Considering the Signal Strength of Su.

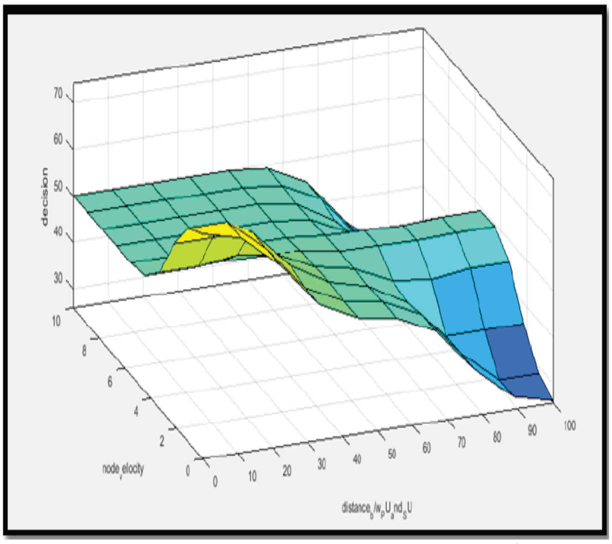


Fig. 4: B) the Opportunistic Spectrum Access Decision Surface by Considering the Signal Strength of SU.

Figure 4 (a), (b) shows the relation between node velocity, distance between primary and secondary user and possibility of taking decision to access spectrum by considering the signal strength of SU. The graph depicts that for the distance ranging from 10m to 20m, the node velocity ranges from 2-4m/s the possibility of decision to access spectrum is high. Table 4 shows possibility of opportunistic spectrum access with respect to node velocity and Distance.

Table 4: Possibility of Opportunistic Spectrum Access and Spectrum Decision

S. No	Node velocity (m/s)	Distance between PU & SU (m)	Possibility to access spectrum (%)	Spectrum Decision
1	9-10	90- 100	1-10	Very low
2	6 – 8	70-80	11-49	Low
3	0 – 5 5 – 10	50-100 0-50	50	Medium
4	2 – 4	10-20	51-90	High
5	0 – 2	0-10	91-100	Very high

Similarly, all cases are observed as shown in the table4

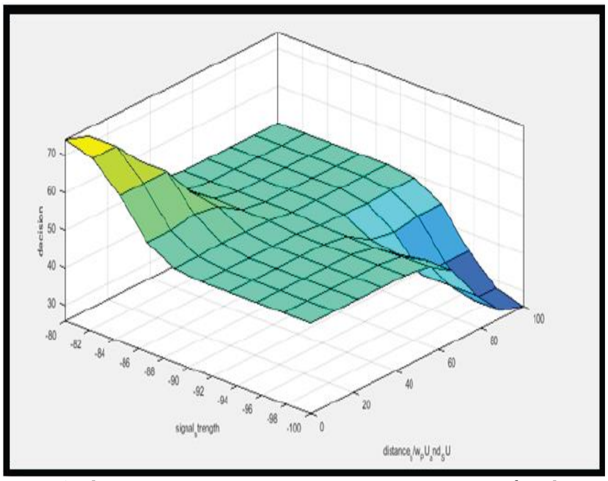


Fig. 5: A) The Opportunistic Spectrum Access Decision Surface by Considering a Node Velocity.

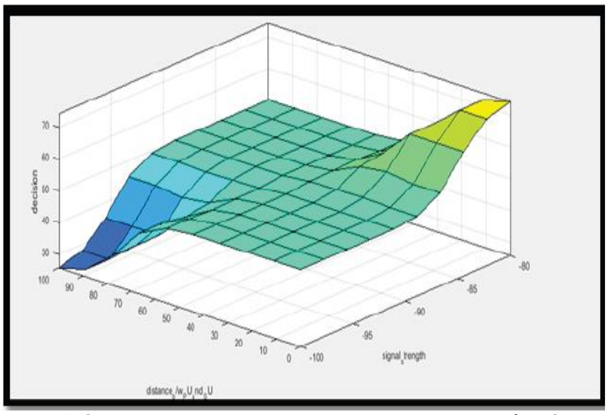


Fig. 5: B) the Opportunistic Spectrum Access Decision Surface by Considering a Node Velocity.

Figure 5 (a), (b) shows the relation between signal strength, distance between primary and secondary user and possibility of taking decision to access spectrum by considering a node velocity. The graph depicts that for the distance ranging from 10m to 20m, the signal strength ranging from -83 to -80 dbm the possibility of decision to access spectrum is very high. Table 5 shows possibility of opportunistic spectrum access with respect to signal strength and distance

Table 5: Possible opportunistic Spectrum Access and Spectrum Decision

S. No	Signal strength (dbm)	Distance between PU & SU (m)	Possibility to access spectrum (%)	Spectrum Decision
1	-100 to -96	90-100	1-10	Very low
2	-96 to -94	70 – 80	11-49	Low
3	-100 to -90 -90 to -80	0 - 50 50 – 10	50	Medium
4	-85 to -82	20- 40	51-90	High
5	-82 to -80	0 -20	91-100	Very high

Similarly, all cases are observed as shown in the table 5.
Figure [6] shows the snapshot of MATLAB code for assigning three different logic values i.e. low=1; medium=2; high =3; to which in turn are assigned to the level of priorities. This results to a stream of eight levels/digits based on the structure chosen. Each logic value is assigned with 16-bit binary equivalent value for three logic values i.e.

Logic value 1=0000000000000001;

Logic value 2=0000000000000010;

Logic value 3=0000000000000011

Therefore, for 8 possibilities each of 16 bits results to 8*16=128bits (on par with IPv6 standards). The three different bandwidths (Bw1, Bw2,Bw3) can be assigned based on information type by observing the 128 bits (i.e. 8 levels*16 bits).
For example,
For The Result Obtained 13311111 - Bw1 Is Assigned;
For The Result Obtained 13311112 - Bw2 Is Assigned And
For the result obtained 13311113 - Bw3 is assigned.

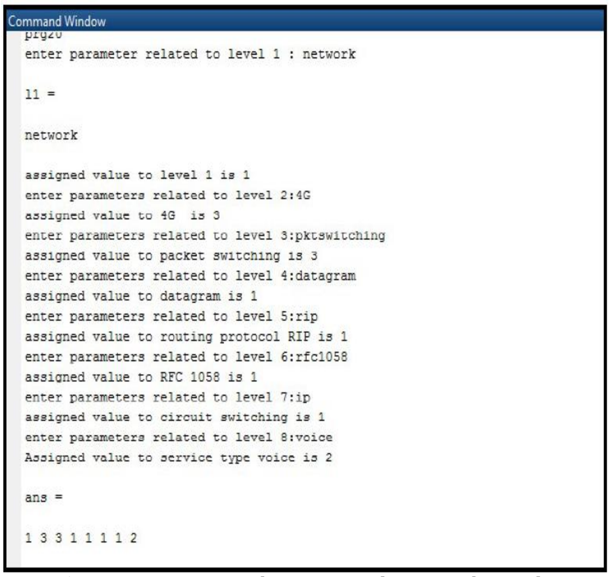


Fig. 6: Assigning Any Three Logic Values to Eight Levels.

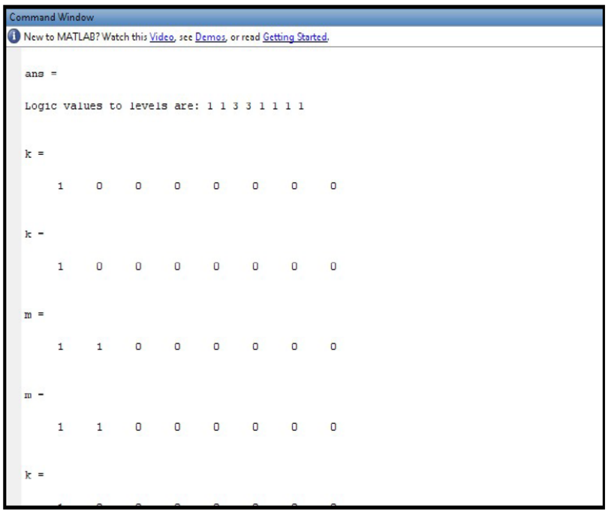


Fig. 7: Assigning Equivalent Bits to Logic Levels.

8. Comparison between various approaches

Opportunistic Spectrum Access (OSA) possibilities with various approaches by considering Node Velocity, Signal Strength and Distance between Primary User (PU) and Secondary User (SU) for different values are shown below:

Case 1:

Types of Approaches	Node Velocity	Signal Strength	Distance between PU & SU	OSA
Primary-Prioritized Markov Approach	9-10 m/s	-100 to -96 dBm	90-100m	Very Low
Spectrum sharing with prioritized primary access	9-10 m/s	-100 to -96 dBm	90-100m	Low
Fuzzy Logic System Approach	9-10 m/s	-100 to -96 dBm	90-100m	Low

Case 2:

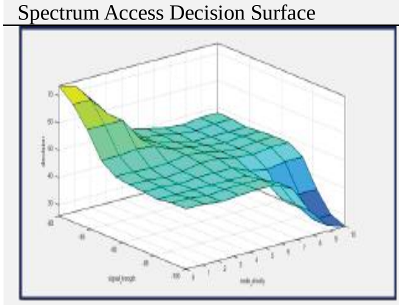
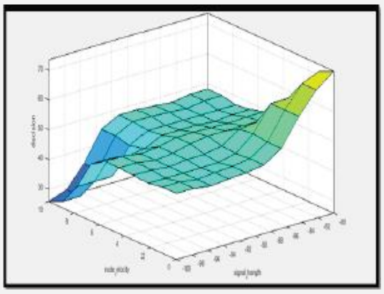
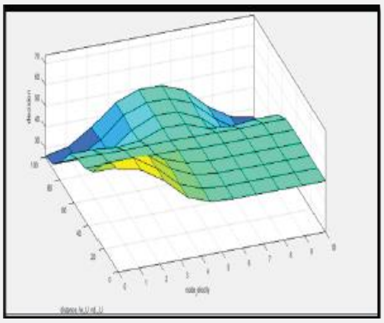
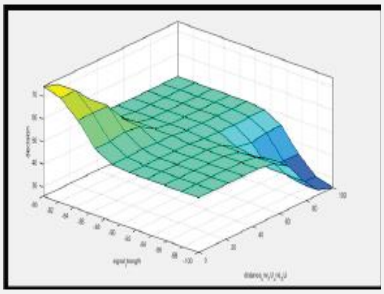
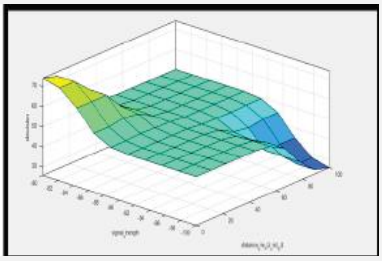
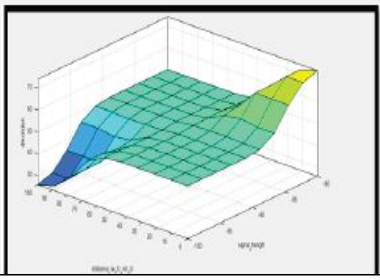
Types of Approaches	Node Velocity	Signal Strength	Distance between PU & SU	OSA
Primary-Prioritized Markov Approach	2 – 4 m/sec	-85 to -82 dBm	10 – 20 m	Low
Spectrum sharing with prioritized primary access	2 – 4 m/sec	-85 to -82 dBm	10 – 20 m	High
Fuzzy Logic System Approach	2 – 4 m/sec	-85 to -82 dBm	10 – 20 m	High

Case 3:

Types of Approaches	Node Velocity	Signal Strength	Distance between PU & SU	OSA
Primary-Prioritized Markov Approach	0 – 2 m/sec	-82 to -80 dBm	0 – 10 m	High
Spectrum sharing with prioritized primary access	0 – 2 m/sec	-82 to -80 dBm	0 – 10 m	High
Fuzzy Logic System Approach	0 – 2 m/sec	-82 to -80 dBm	0 – 10 m	Very High

9. Conclusion

The proposed approach using a Fuzzy Logic System detects the possibility to access spectrum for effective utilization by secondary users. The decision for secondary users are selected based on QOS parameters. Our proposed Fuzzy Logic System has been used for Efficient Spectrum decision and channel assignment which avoids multiple users from collision. Therefore, the secondary user with the highest possibility has guaranteed to access the spectrum. Once secondary user has been decided based on the type of service, the available spectrum is assigned meticulously for proper utilization of the available channel bandwidth. The summary of Fuzzy Logic Design for Cognitive Radio Networks for Efficient Spectrum Decision and Channel Assignment is given below.

Spectrum Access Decision Surface	Node Velocity	Signal Strength	Distance between PU & SU	Spectrum Decision
 	9 – 10 m/sec	-100 to -96 dBm	90 – 100 m	Very Low
 	2 – 4 m/sec	-85 to -82 dBm	10 – 20 m	High
 	0 – 2 m/sec	-82 to -80 dBm	0 – 10 m	Very High

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