

# Intelligent Process of Spectrum Handoff in Cognitive Radio Networks

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## Abstract

*Spectrum handoff is a crucial function of Cognitive Radio (CR) which is the change of operating frequency. The main problem in spectrum handoff is the time taken in the searching, selection, and switching to a new available channel which can cause a significant amount of delay during spectrum handoff. This research aims to minimize the delay that occurs during spectrum handoff. A Proactive Fuzzy-Based Backup Channel Selection Scheme (PFBBCSS) was proposed where the Secondary User (SU) gathers backup channels in advance before the return of the Primary User (PU), then fuzzy logic would be used for the selection of the best channel out of the available backup channels. The proposed scheme was simulated and evaluated using the MATLAB Simulation tool and the result was compared with a Pure Proactive Spectrum Handoff Scheme. Results showed, in terms of throughput and efficient time utilization under a varying number of licensed channels, that the proposed scheme performed better, making it a good mechanism to be used for handoff decisions by the Secondary User (SU).*

**Keywords:** Cognitive Radio Network, Spectrum Handoff, Fuzzy Logic, Handoff Delay

## 1. Introduction

The emerging needs of wireless data services such as the 5G technology (Salami et al., 2019; Popoola et al., 2017), public safety communications (Faruk et al., 2018a), e-health, and virtual clinics (Faruk et al., 2017; 2020), there is a need for a more enhanced capacity in the wireless systems. The static (conventional) spectrum allocation to Primary or Licensed Users (PU) limited the overall utilization of the spectrum since the spectrum may not be completely utilized by the PU all of the time and in all locations, thereby, pushing more pressure on the already exhausted radio spectrum frequencies (Somawanshi et al., 2016; Oloyede et al., 2017; 2019; Oloyede & Faruk, 2018).

Several researches that conducted spectrum occupancy measurements and analyses, aimed at assessing the utilization of the spectrum allocated to PU, findings show low occupancy rates, with average utilization of less than 10% (Faruk et al., 2014; 2016; 2018b; 2019; Ganiyu et al., 2019; Babalola et al., 2015a; 2015b). However, Cognitive Radio (CR) was developed, which allows Secondary or Unlicensed Users to utilize or share the unused licensed frequency allocated to the PU. The major purpose of developing cognitive radio is to enable wireless transmission adaptation through Dynamic Spectrum Access (DSA) to maximize the usage and benefits associated with fixed spectrum assignment (Westphall & Westphall, 2011). The application of CR has been demonstrated for television bands (i.e., TV white spaces) (Adediran et al., 2014; Faruk et al., 2015).

Spectrum management includes having a reliable Medium Access Control (MAC) Protocol that regulates the access to the spectrum by the SUs, thereby coordinating the access of SUs to the free spectrum (holes) and vacating the spectrum on return of the PUs (Faruk et al., 2012; 2013). Spectrum mobility refers to the mechanism by which

Cognitive Radio hops between multiple spectrum holes, while, preserving seamless communication requirements throughout transitions to a better spectrum. Spectrum Mobility can be classified into two; Spectrum Handoff and Connection Management. This research is, however, limited to Spectrum Handoff without considering the other functionalities of CR. Spectrum Handoff is the transmission of data from one working channel to another void channel or hole without interrupting the present connection or losing the data that is being conveyed.

When a Primary User (PU) returns to the channel, the Secondary User vacates the channel and accesses a new channel to complete its unfinished transmission (Mardini et al., 2018). The main problem with spectrum handoff is the time required to search, select and switch to available channel. This research aims to reduce the time it takes to find a new available channel, thereby, reducing Spectrum Handoff delay. This is achieved by designing and simulating a Fuzzy Logic algorithm for effective spectrum handoff in CRN. This paper is structured in the following: the related works are presented in Section 2; the research methodology employed in the work is provided in Section 3; the results are presented in Section 4, while, the paper is concluded in Section 5.

## 2. Related Work

This section presents a brief discussion of the existing literature on fuzzy logic in Cognitive Radio Networks as various techniques have been proposed by different authors.

In Giupponi and Pérez-Neira, (2008), a Fuzzy-based technique was presented and implemented with two Fuzzy Logic Controllers (FLCs) where FLC1 was used to estimate the distance between the Primary User and Secondary User, and FLC2 was used to make Spectrum-Handoff decision. Results showed that the proposed scheme outperformed a solution based on predefined thresholds when compared in terms of spectrum handoff rate and interference temperature recorded at the PU receiver. A Fuzzy Power Control Scheme that will enable Secondary Users to alter their transmit power within the tolerable interference limits and switch between frequency bands was proposed by Kaur et al. (2009). Two Fuzzy Logic Controllers (FLCs) were utilized where FLC1 was used for power control and FLC2 was used for Spectrum mobility. Results demonstrated that lowering the number of handovers is possible when the Secondary User's transmit power is controlled within the interfering tolerance limits.

In Tabakovic et al. (2009), a Fuzzy Logic transmit-power control was proposed which allows Secondary Users to achieve the desired transmission rate and quality while limiting interference to primary and other concurrent secondary users. The proposed scheme was simulated and results showed that Fuzzy-Logic transmit power controller keeps a constant Secondary User receiver SINR with  $\pm 1$  dB deviation compared to the required SINR. Fuzzy logic was used in Kaur et al. (2010) to analyze a decision-making process that allows secondary users to make effective utilization of the spectrum frequency in terms of the secondary user's velocity, the spectrum to be used by the secondary user, and the distance of the secondary user from the primary user. Results showed that if the distance between licensed and unlicensed users is small and the velocity of the secondary user is high, then the probability of making a decision increase.

In Lala et al. (2013), a novel spectrum handoff algorithm for cognitive radio networks based on a fuzzy logic approach was presented which made use of two Fuzzy Logic Controllers (FLCs) where FLC1 was used to calculate the optimal transmission power for Secondary User (SU) to minimize interference to Primary User (PU) and FLC2 was used to make handoff decisions based on knowledge of transmission power, data rate, and Holding Time (HT) (i.e., average idle duration) of a channel. Results showed that the maximum value of  $SU_{POWER}$  is obtained when  $R_{POWER}$  is at its minimum and  $T_{POWER}$  is at its maximum. Somawanshi et al. (2016) provided a comprehensive explanation of Cognitive Radio, including the requirements and physical architecture of Cognitive Radio as shown in fig 1;

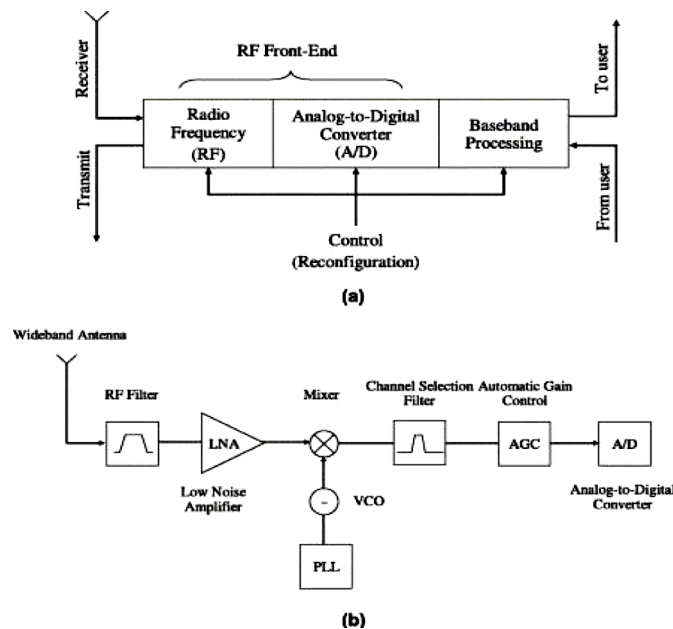


Figure 1: Physical architecture of the cognitive radio (a) Cognitive radio transceiver and (b) wideband RF/analog front-end architecture. (Source: Somawanshi et al. 2016)

Spectrum awareness was also presented as a crucial element of a Cognitive Radio, which is the radio's ability to acquire, measure, sense, learn, and be aware of the radio's operational environment to recognize spectrum space opportunities and use them efficiently for adaptive transmission. The study was limited to presenting motivation for advancements in opportunistic spectrum access, an overview of cognitive radio systems, and important technical and scientific concerns in cognitive radio; thus, no experiment or simulation was performed. A Pure Proactive Spectrum technique was proposed in Metti et al. (2014) where the Secondary User (SU) uses both Proactive Spectrum Sensing and Proactive Handoff Action to anticipate the Primary User's arrival and evacuate the channel before it arrives.

The proposed scheme was simulated using the Fuzzy Logic approach to make accurate decisions and the Artificial Neural Network (ANN) technology to predict channel availability. Results showed that if both the BER of SU and the BER of PU are medium, an SU Power Decrement is required but no Handoff (HO) is required. In Bayrakdar and Calhan (2015), a Fuzzy logic-based spectrum handoff decision mechanism was proposed which takes into account different data traffics such as audio and video traffic. Three inputs parameter was used; data rate, channel usage, and priority with one output Handoff probability (probHandoff). Results showed that for audio traffics, handoff probability increases with an increase in data rate, but for the effect of other input parameters, handoff probability remains the same even if the data rate increases in some values while for video traffics, handoff probability decreases as the data rate increases.

In Wang et al. (2015), a fuzzy-based dynamic channel allocation scheme was proposed in which the received signal strength was used to determine the channel access priority of secondary users (SU). Four input parameters were utilized; Spectrum Utilization Efficiency, Mobility, Distance, and Signal Strength to provide a Priority Factor as an output. Results showed that the proposed outperformed Kaniezhil's scheme and the Random Channel Assignment scheme in terms of total secondary network throughput and the Signal-to-Noise (SNR). In Alhammadi et al. (2016), a Fuzzy-based negotiation was proposed which made use of Two Fuzzy Logic Controllers (FLCs) where FLC1 was used to estimate the probability of successful negotiation between PU and SU, and FLC2 was used to estimate the probability of successful negotiation for pricing and duration between PU and SU. Results

showed the percentage of successful negotiation, percentage of returned negotiation, probability of successful negotiation with three different Price Rates of Primary User, and Handoff delay of different rates of Primary Users.

In Salgado et al. (2016), a Fuzzy algorithm for the spectrum decision function was proposed specifically for the selection of a backup channel in spectral mobility based on multiple criteria, using data obtained from the Wi-Fi frequency band. The proposed scheme was then compared with an Advanced Hierarchical Process (AHP) and results obtained by experimental data from the Wi-Fi frequency band – 2.4 GHz to 2.5 GHz showed that the Fuzzy Algorithm outperformed AHP by having a low rate of channel change when compared with using three different metrics.

A Fuzzy-based support system that deals with channel selection and channel switching to improve the overall throughput of Cognitive Radio Networks was proposed by Ali et al. (2019) which made use of two Fuzzy Logic Controllers (FLCs). FLC1 was designed to estimate the power at which the SU can transmit its data without interfering with the Primary User and other Secondary Users' transmissions while maintaining a certain QoS for its transmissions and FLC2 was used to select the best channel from a list of available channels, allowing the SU to use a channel for an extended period while gradually decreasing the channel switching rate. Results showed that the proposed scheme outperformed a conventional scheme in terms of the number of handoffs, Throughput, and Time consumed for channel selection under conditions such as varying transmission times, varying number of SUs, and a varying number of licensed channels.

In the review of existing literature briefly discussed above, it can be seen that fuzzy logic has been proven to be a useful technique used in Cognitive Radio Network although, most research work focused on using the fuzzy logic algorithm for either spectrum handoff-decision or to regulate the transmit power of the Cognitive Radio (CR) while sharing the same channel as the Primary User in order not to cause interference and complete its transmission. Other research work focused on the comparison between Fuzzy Logic Algorithm and some other conventional schemes in which fuzzy logic outperforms in each case. But no research has strictly focused on minimizing the delay during spectrum handoff hence the need for further studies to investigate how the time taken to search, select and switch to a new available channel can be minimized to increase the overall throughput of the network.

### 3. Research Methodology

This research utilized MATLAB Fuzzy Logic Toolbox 2021a for simulation and analysis of Fuzzy logic for the selection of a backup channel for spectral mobility in Cognitive Radio Network (CRN) as well as investigated how the Secondary User (SU) used fuzzy logic to select a better backup channel during handoff in cognitive radio network to minimize the spectrum handoff delay thereby increasing the overall throughput in terms of Channel Transmission Range ( $Ch_{TR}$ ) and Channel Rank ( $Ch_{Rank}$ ) which was the two inputs parameters utilized with one output of Select Channel ( $Sel_{CH}$ ). This research would follow the procedure as shown in fig 2;

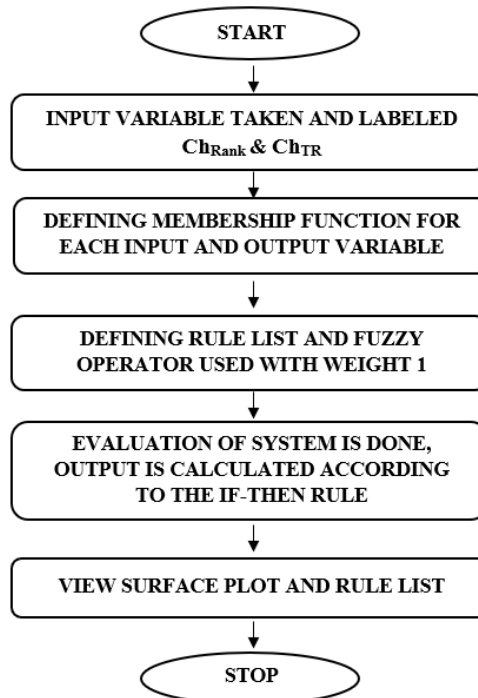


Figure 2: Flow Chart showing the research process followed

#### 4. Proposed Fuzzy-Based Channel Selection Scheme

In this section, a brief discussion on the significance and working of Fuzzy Logic as well as the selected parameters that were used to simulate the fuzzy logic controller is presented and the workings of the proposed fuzzy logic controller to minimize the spectrum handoff delay and to improve the throughput of the system while selecting the best available channel in the cognitive radio network.

##### 4.1 Significance and Workings of Fuzzy Logic

Fuzzy Logic is a mathematical technique that is best suited for decision-making especially when all the input values are not precise and qualitatively ambiguous. It is a multivalued logic that allows the definition of intermediate values between standard evaluations such as yes & no, true & false, hot & cold, high & low, etc. A fuzzy logic controller (FLC) can be used to implement decision-making processes and it consists of four modules as shown in figure 3;

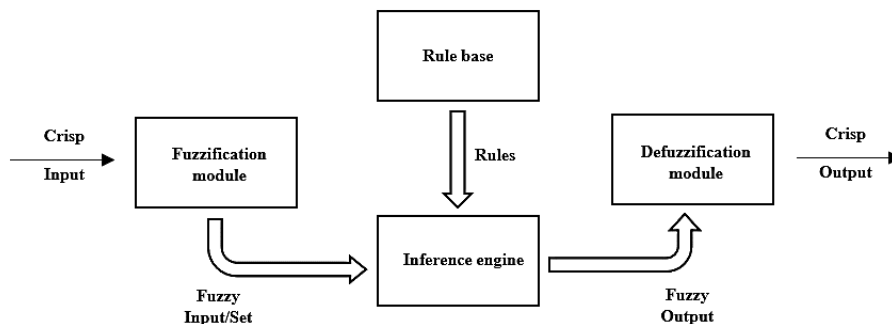


Figure 3: The Flowchart of a Fuzzy Logic Controller (FLC)



1. Fuzzification module: this module does the conversion from a numerical value that is the crisp inputs or real inputs into fuzzy inputs based on the membership functions that are stored in the fuzzy rule base.
2. Fuzzy Rule base: this module contains the IF-THEN conditions also known as rules as well as the membership functions that regulate the decision-making in the fuzzy logic system.
3. Fuzzy Inference Engine: This module is for determining the ideal rules for a particular input. The fuzzy output is then generated by applying these rules to the input data.
4. Defuzzification module: This module converts the fuzzy outputs from the inference engine into crisp outputs. The defuzzification method adopted for this research is the Centroid method, also known as the Center of Gravity (CoG) method, and can be represented mathematically as for two inputs  $x_1$  and  $x_2$ ;

$$y(x_1, x_2) = \frac{\sum_{l=1}^M \mu_{F_1^l}(x_1)\mu_{F_2^l}(x_2)C_{avg}^l}{\sum_{l=1}^M \mu_{F_1^l}(x_1)\mu_{F_2^l}(x_2)} \quad (1)$$

Where;  $y$  is the output while  $x_1$  and  $x_2$  are the two inputs,  $M$  is the number of rules,  $\mu_{F_1^l}$  is the membership function and  $C_{avg}^l$  is the Centroid of the  $l$ th rules fuzzy sets

#### 4.2 Selection of Parameters

This paper proposed a Proactive Fuzzy-Based Backup Channel Selection Scheme (PFBCSS) where a Secondary User maintains a list of available channels in advance before the arrival of the Primary User (PU) so that it can handoff to an idle channel quickly to avoid having interference with the Primary User and to complete its transmission. To choose the best channel out of the pool of available channels already gathered, the Secondary User (SU) then uses the Fuzzy Logic based on the input parameters to select the best channel. This scheme utilized one Fuzzy Logic Controller (FLC) which is used for making the selection decision based on the two selected input parameters:

1. Channel Rank ( $Ch_{Rank}$ ): This is a channel indexing technique that allows SUs to choose the best and most stable channel from a pool of idle channels. This parameter returns the availability of Primary User (PU) activity-aware channels.  $Ch_{Rank}$ -indexed channels are more stable, with fewer collisions and less interference from PUs. That is, the selection of channels based on  $Ch_{Rank}$  provides the lowest possible channel switching rate and also the ability to perform quick switching decisions. The Channel Ranking algorithm only returns the ranks of available channels at any given time without considering busy or unavailable at that time. Channel Rank can be represented mathematically as;

$$Ch_{Rank} = \frac{TFT}{(TUT \times TNPA) + TFT} \quad (2)$$

Where;  $TFT$  denotes the Total Free Time,  $TUT$  denotes the Total Utilization Time that is the Total busy time measured over the channel at a particular time, and  $TNPA$  denotes the Total Number of Primary User (PU) Arrivals detected over the channel within a given time

2. Channel Transmission Range ( $Ch_{TR}$ ): This is the maximum distance between two communicating nodes. A transmission can be considered to be a success only when the receiving node is out of the interference range of the corresponding sending node and within the transmission range. Different channels available to the Secondary User (SU) have different transmission ranges – heterogeneity of available channels. Lower transmission range channels have higher frequency bands as frequency is inversely proportional to wavelength which can be sometimes regarded as distance/range. Channel Transmission Range can greatly reduce channel switching because when the transmission range between two communicating pairs of Secondary Users nodes is enough to span the distance between them, channel switching will be reduced.

#### 4.3 Proposed Fuzzy Logic Controller

This paper utilized one Fuzzy Logic Controller (FLC) for the selection of the best channel out of the available backup channels, allowing the Secondary User (SU) to quickly choose a more reliable channel with minimal interference from the Primary User (PU) or other Secondary Users.

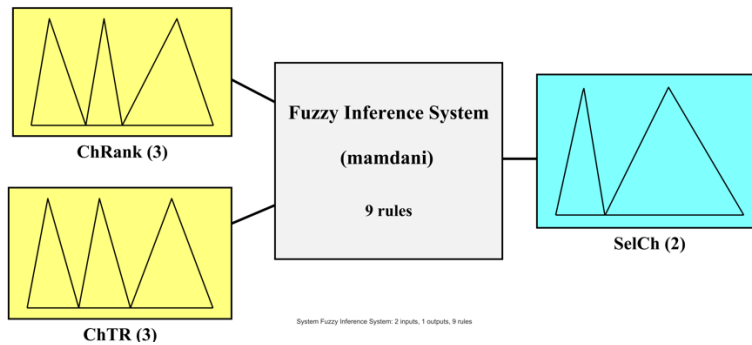


Figure 4: The flowchart of the Fuzzy Logic Controller (FLC)

Before the selection of a new channel, the Secondary User first considers the two input parameters  $Ch_{Rank}$  and  $Ch_{TR}$  which will then be passed into the Fuzzification module to get the membership functions shown in figure 5. Then the Fuzzy Inference Engine applies the rules, presented in table 1, on each input parameter and then forwards them to the Defuzzification Module to get the crisp output where the Secondary User (SU) will make the appropriate selection of the best available backup channel.

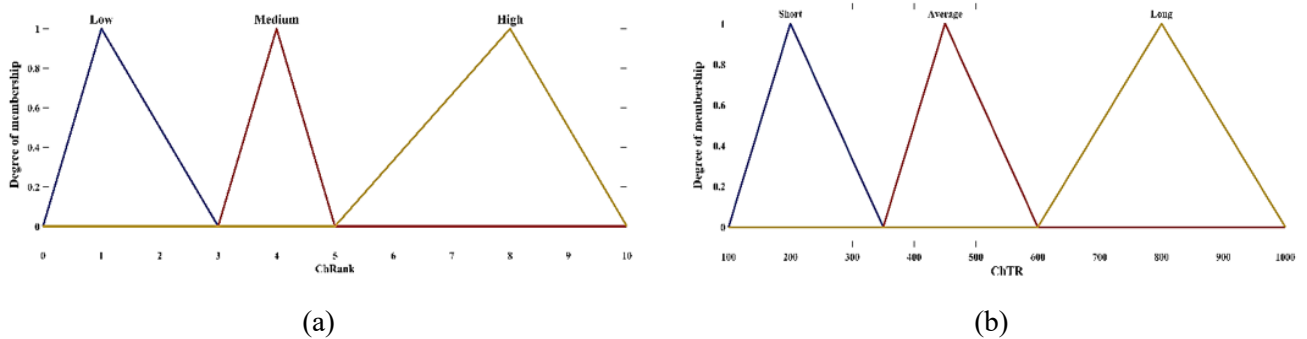


Figure 5: Membership functions for FLC (a) Channel Rank ( $Ch_{Rank}$ ) and (b) Channel Transmission Range ( $Ch_{TR}$ )

A total of 9 rules were utilized for the Fuzzy Logic Controller as presented in Table 1. The total number of rules was utilized because only two input parameters were used.

Table 1: Inference Rules for the Fuzzy Logic Controller

Rule Number	$Ch_{Rank}$	$Ch_{TR}$	$SelCh$
1	Low	Short	×
2	Low	Average	×
3	Low	Long	✓
4	Medium	Short	✓
5	Medium	Average	✓
6	Medium	Long	✓
7	High	Short	×
8	High	Average	✓
9	High	Long	✓

Where Symbol;  
 × denotes No  
 ✓ denotes Yes

### 5. Simulation of the Proposed Scheme

For the successful simulation, this research assumed that there are only 10 available backup channels and random values were assumed for both Channel Rank and Channel Transmission Range which will form the crisp inputs.

Table 2: Simulation Parameters

Parameters	Values
Simulation time	10-20 seconds
Total available channels	10 channels
Channel Rank	0 – 10
Channel Transmission Range	100 – 1000 meters
SU Waiting time	5 seconds
Total time required to search and select a channel	5 seconds
Packet Size	1024 bytes
Number of Secondary Users	20

To simulate the proposed model, a MATLAB code was written where the already designed Fuzzy Logic model was integrated into the code to select the best channel from the list of ten available channels. The code is divided into four main sections;

1. Setting the number of Available Channels: here the number of available channels was set to 10 and other variables such as some arrays required in the program were defined as well.
2. Taking input data: upon running the MATLAB code, three inputs are requested, namely; the Channel number used to identify each channel, the value of the Channel Rank of that particular channel, and finally, the value of the Channel Transmission Range of that particular channel. These values will then be fuzzified and mapped to their respective linguistic variable such as the those defined earlier – Low, Medium, or High for Channel Rank as well as Short, Average, or Long for Channel Transmission Range.
3. Opening FIS created using Fuzzy Logic Toolbox: in the section, the Fuzzy Logic Model that has been created using the Fuzzy Logic Toolbox is then called using the function `readfis()`. The fuzzy logic then applies the rules on the input parameters based on the linguistic variable and then outputs the defuzzified value (crisp output).
4. Selecting the best channel: this is the last section and where the best channel is selected based on the highest defuzzified value (crisp output) obtained from the previous section. The result of the code is then outputted stating the best channel out of the available backup channels.

#### 5.1 Simulation Results

In this section both the result obtained from the fuzzy logic toolbox simulation and the MATLAB code simulation is presented.

The 3D graph shown in figure 6 presents the inputs–output relationship for the Fuzzy Inference System (FIS) that describes the output decision based on the inference rules and the input parameters –  $Ch_{Rank}$  and  $Ch_{TR}$ .



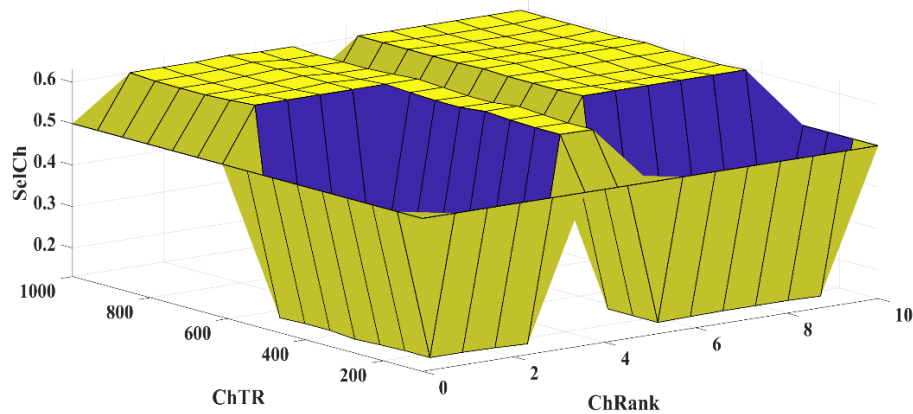


Figure 6: 3D-Graph showing the input-output relationship for the Fuzzy Logic System

The results of the MATLAB code written to simulate Fuzzy Logic for the selection of the best available backup channel are shown below;

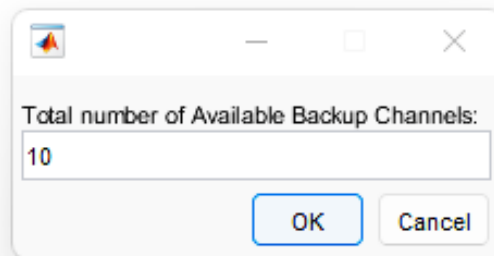


Figure 7: Setting the total number of available backup channels

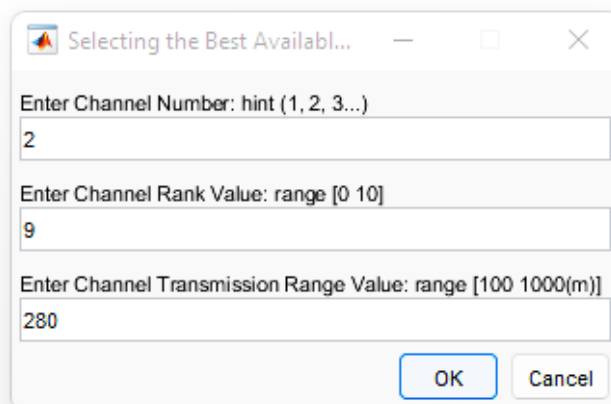


Figure 8: Entering the assumed values of the input parameters

The above dialog box shown in figure 8 will run 10 times for all 10 available backup channels to correctly accept the values of the input parameters for each channel. After all values for the input parameters for each channel has

been entered, the code was written to output all inputted values and their corresponding linguistic variable as shown in figure 9;

list_names	list_chRank	chosen_chRank	list_chTR	chosen_chTR
"1"	2	"Low"	500	"Average"
"2"	9	"High"	280	"Average"
"3"	7	"High"	650	"Long"
"4"	4	"Medium"	170	"Short"
"5"	4	"Medium"	450	"Average"
"6"	8	"High"	870	"Long"
"7"	6	"Medium"	700	"Long"
"8"	7	"High"	200	"Short"
"9"	1	"Low"	150	"Short"
"10"	2	"Low"	900	"Long"

Figure 9: Image showing the output of the values inputted

Then, values are transposed into rows and columns for each of the 10 available backup channels after which the values are defuzzified based on the rules defined for the Fuzzy Logic Controller (FLC), and the channel with the highest defuzzified value is chosen to be the best channel as shown in figure 10.

```

0.1346
0.1344
0.6277
0.6224
0.6210
0.6229
0.6266
0.1356
0.1346
0.6245

The best Channel is Channel 3
..
    
```

Figure 10: Image showing the defuzzified crisp values and the selected channel

The best channel selected is Channel 3 which has an assumed Channel Rank of 7 and a Channel Transmission Range of 650m which based on the membership functions are seen to be High and Long respectively. It was chosen to be the best channel because it has the highest defuzzified value of all the available backup channels.

**6. Performance Evaluation of the Proposed Model**

The proposed scheme was evaluated against a conventional scheme proposed in [26], which is a pure proactive spectrum handoff where the Secondary User (SU) chooses a channel randomly out of the available channels. However, in the proposed scheme, the Fuzzy Logic decision model is used to choose the best channel out of the available channels rather than selecting randomly. The performance is evaluated in terms of the average throughput and the total time used for channel selection under a varying number of channels.

$$Throughput = \frac{\sum Packet\_size}{Total\ Transmission\ time} \quad (3)$$

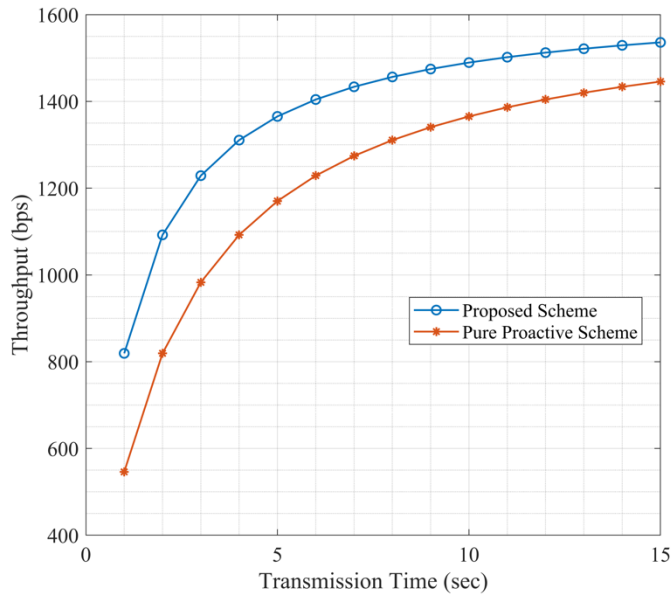


Figure 11: Throughput against Transmission time

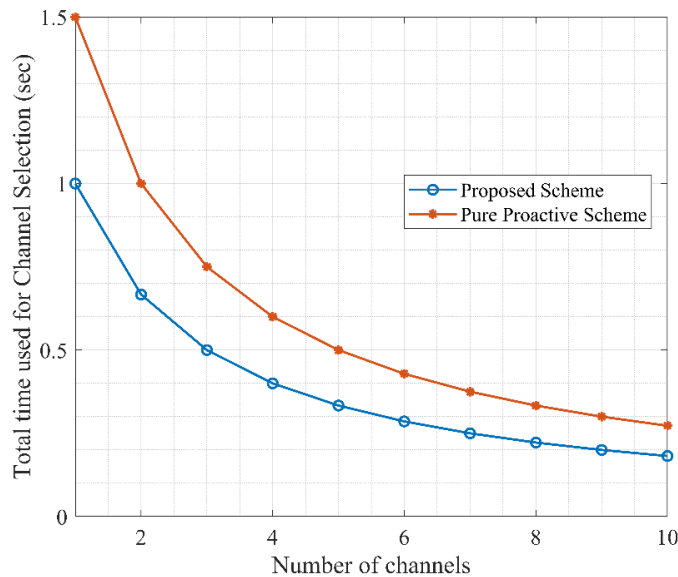


Figure 12: Total time used for channel selection under a varying number of channels

### 6.1 Discussion

The overall throughput and the total time required for channel selection for the proposed model was measured for 10 licensed channels for a total of 15 seconds and the results are compared with a pure proactive scheme as shown in Figs 11 and 12. Findings from the Figures revealed that the proposed scheme performed better than the conventional scheme in terms of data packet transmission success and efficient time utilization under a varying number of licensed channels. This is because the proposed scheme employs a fuzzy logic algorithm to select the

best channel based on the channel rank (ChRank) and the channel transmission range (ChTR). The channel rank provides more stable channels, with fewer collisions and less interference from PUs, and the channel transmission range provides enough communication range to span the communicating SU node pair leading to quick handoff decision-making. Hence, the lesser time spent to search and select a new channel will lead to a faster spectrum handoff which eventually increases the overall throughput of the system.

## 7. Conclusion

Spectrum Handoff is one of the functions of Cognitive Radio where a Secondary User can change its operating channel to continue its transmission and not cause interference with the Primary User. However, during spectrum handoff, the time taken to search, select, and switch is considerably much causing a spectrum handoff delay which in turn reduces the overall performance of the network. This research has proposed a Proactive Fuzzy-Based Backup Channel Selection scheme to minimize spectrum handoff delay which when compared, using MATLAB simulation tool, with a Pure Proactive Spectrum Handoff performed better by a throughput of 90bits/sec and in terms of efficient time utilization under a varying number of licensed channels. Further research should employ the use of more than two input parameters as well as more performance metrics for evaluation.

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