Fuzzy Tree Schematic for Spectrum Handoff Reduction in Cognitive Radio Networks

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Abstract*—Spectrum is a limited resource, so it must be used effectively. The fixed spectrum allocation method currently in operation may not sustain the growth in the network access users, which continues to increase over time. Many studies have shown that the spectrum deficiency problem can be solved with cognitive radio network (CRN) technology. CRN allows flexible spectrum utilization. Spectrum handoff is one of the fundamental prerequisites for dynamic spectrum access in cognitive radio networks. The ping-pong effect is one of the problems caused by the frequent occurrence of unnecessary handoff spectrum. So, in CRN, the right handoff decision is needed to avoid the ping-pong effect. The proposed fuzzy system carries the concept of a fuzzy tree that uses two fuzzy inference systems (FIS), which work in two stages, namely FIS-1 and FIS-2. In the early stages, the FIS-1 controls the secondary users (SU) power and prevents interference with the primary users (PU). FIS-2 is used to execute precise spectrum handoff decisions. The test results show that the amount of handoff spectrum has decreased by up to 43 % compared to other methods, which are only 60 %. This results in a decrease of 16.67% from the previous method. Thus, the ping-pong effect can be minimized with the right handoff decisions.

***Keywords*—spectrum handoff, ping-pong effect, cognitive radio network, fuzzy tree, fuzzy inference system**

I. INTRODUCTION

In recent years, the Cognitive Radio Network (CRN) has drawn attention because it provides a viable solution to the issue of spectrum shortage [1]. CRN offers more efficient spectrum allocation because using flexible spectrum management techniques can help minimize interference and react right away to the availability of spectrum bands. Cognitive radio may adjust its transmitter settings based on the surrounding environment [2]. Studies indicate that most of the frequency bands that are currently available are overloaded with heavy traffic and that these conditions are causing an issue with spectrum scarcity that is expected to arise in the future [3].

Manuscript received September 6, 2022; revised February 15, 2023; accepted February 22, 2023.

Primary Users (PU) and Secondary Users (SU) are two categories of users in CRN. PU has precedence over SU because it is licensed to utilize the spectrum. The capacity of SU to intelligently assess the band's availability and select the band where the PU is not using it is crucial because SU is an unlicensed user who accesses the network when the opportunity arises [4, 5]. Spectrum sensing entails detecting nearby RF frequencies that aren't utilized by the PU now [6]. The spectrum determination function helps the SU decide which spectrum port to use for its opportunistic transmission, independently or with network assistance. Spectrum handoff can be conducted when an empty channel is available. However, switching channels or bands for spectrum handoff can lead to other issues, such as ping-pong effects [5]. The ping-pong effect in this study can be viewed as a research gap because according to numerous related studies, it hasn't been generally considered when making judgments on spectrum handoff [6].

Spectrum handoff occurs when the SU switches to a different operating frequency. The factors that cause SU to switch are PU using its channel, the presence of PU when SU is using its track, and a decrease in the quality of the current channel. In addition, PU interference during transmission and SU outside the coverage area is also a factor in the occurrence of spectrum handoff. As a result, the spectrum handoff procedure should proceed with the least amount of delay possible [7, 8]. Fuzzy logic can be helpful in modeling situations where typical mathematical techniques are ineffective, such as when the information supplied is imprecise and insufficient. Fuzzy sets and fuzzy logic's inference rules are understandable by humans, ensuring an effective solution to a problem [6–8].

The following are the contributions of this work:

- Suggest a fuzzy inference system model that handles the proper spectrum handoff decisions in Cognitive Radio Networks using a fuzzy tree concept that combines FIS-1 and FIS-2.
- Considering the variable Psu which is the output of FIS-1, in preventing interference with the PU.
- Consider the SU speed variable set to FIS-2 to minimize the ping-pong effect by creating a suitable threshold to reduce spectrum handoff.

The remainder of this essay is organized as follows: Section II gives an overview of cognitive radio, includes a survey of the literature on cognitive radio networks, and discusses fuzzy logic, ping-pong effects, and spectrum handoff as decision-making tools. Simulations of current and related system models are presented in Section III. Additionally, this part identifies the flaws in the suggested model and evaluates how well the fuzzy tree system addresses the ping-pong effect's root causes. In Section IV, we'll talk about how the fuzzy tree system model compares to the current system model through simulation, analysis, and comparison. The conclusions and future work are presented in Section V.

II. Related Works

An intelligent wireless communication system known as a cognitive radio network uses techniques to develop a learning understanding of its surroundings, adapt to its operational environment, and dynamically modify radio operational settings appropriately (e.g., transmit power, the carrier frequency). real-time (including modulation method) [7].

PU and SU require a high degree of adaptability at the CRN. By enabling unlicensed users to temporarily access unused spectrum when authorized users aren't using it, therefore cognitive radio can significantly improve spectrum efficiency [2, 8, 9]. When the primary spectrum user is not using it, secondary users might benefit from the empty spectrum thanks to cognitive radio networks' dynamic access [10, 11].

One of four crucial cognitive radio functions is spectrum mobility. Spectrum mobility seeks to preserve SU's continuing communication performance [4, 10]. Spectrum mobility is a problem that arises when primary users want to use a licensed spectrum that secondary users are operating at a specific time, which requires the latter to stop the channel they are now using immediately. Spectrum handoff and connection management are the two procedures that make up spectrum mobility. The process of shifting an active data transmission across a different channel than it is currently using is known as a spectrum handoff. Regarding connection management, it aids in preserving the connection during the handoff procedure [9, 11, 12]. To facilitate the future transmission of secondary user data, proper processes should be established to discover acceptable alternative channels [10, 11].

Reactive and proactive spectrum handoff sensing are two different types of spectrum handoff sensing [13, 14]. In situations where the cell size is small in comparison to the average mobile station (MS) speed, a handoff is crucial [15, 16]. Cell size may be inversely correlated with the rate of handoff [10]. Because the current network is heterogeneous and the cell size is heterogeneous, the spectrum handoff process in cognitive radio networks is more complicated and demands greater accuracy. Making judgments to perform spectrum handoff in an uncertain cognitive radio network environment calls for applying and using fuzzy logic theory. A solution based on fuzzy logic is suggested in [8] to handle the handoff spectrum. The system is made to adjust the level of interference distance between PU and SU by monitoring the power of SU. If SU interferes with PU's signal, the suggested technique efficiently handles the spectrum handoff. Systems using fuzzy logic effectively cope with fading channel uncertainties, route loss, and the heterogeneity of wireless environments [9].

Aggarwal and Velmurugan *et al*. [11] focused on the problems faced during spectrum handoff. It presents a hybrid spectrum handoff technique using a probabilistic approach through a centralized device to address the shortcomings of existing techniques in performing spectrum handoff. This approach centralizes the SU function in one device, which allocates channels to SU using a probabilistic approach in an order based on the PRP M/G/1 queueing model.

Naeem *et al*. [6] focused on reducing the ping-pong effect of spectrum handoff in Cognitive Radio Networks. Ping-pong effect reduction is possible if an efficient decision is made to execute spectrum handoff, thus avoiding unnecessary handoffs. The study has used a hybrid concept that applies two fuzzy inference systems.

Gul *et al*. [13] examined a multi-channel access issue in a cognitive radio network with M primary users and a secondary user (SU) with multiple channels. The SU chooses K channels for data transmission without information about the channel states or their evolution process statistics. When the SU detects an available channel, it sends data at that moment. If not, it does not use the track. The myopic policy is presented, and its upper limits of throughput performance are calculated based on average throughput criteria. The results indicate that the shortsighted policy can attain optimality under certain channel evolution processes for block fading channels, although it is generally not optimal.

Gul and Kantarci *et al*. [12] focused on using cognitive radio technology in-vehicle communication. The goal is to build cognitive radio-equipped vehicles to take advantage of the licensed spectrum on the road. The study tackles a scenario with M primary users and receivers and secondary users with K channels and receivers. The secondary user selects the K channel to transmit data at each time slot and switches to another channel if the selected channel is in bad condition. This study presents the Uniforming Random Ordered Policy (UROP) and shows that it achieves nearly optimal throughput under the average reward criterion and block fading assumptions. Numerical results show that UROP achieves more than 80% optimal throughput compared to less than 25% achieved by other methods.

Ali *et al*. [14] addressed the problem of minimizing the handoff spectrum rate by using two effective approaches, interweave and underlay. The interweave approach selects the best channel for transmission, while the underlay approach minimizes the SU transmission power to increase the final network throughput while minimizing the channel handoff rate. Channel handoff and selection decisions must be handled together and consider the impact on the PU and SU needs. This research adopts a hybrid approach and shows more effective results using a fuzzy logic-based decision support system than a conventional cognitive radio network.

Maheshwari and Singh [15] proposed a fuzzy logic-based scheme to make better and more efficient channel handoff decisions. This scheme uses interference, bit error rate, and signal strength as decision parameters. A trained neural network is also used to measure channel strength based on fuzzy patterns.

The existence of a power readjustment process may result in signal variances, and this circumstance may raise the number of handoffs required to gain additional spectrums. The ping-pong effect is the name given to this pointless and excessive handoff. The network must make some precise and effective handoff decisions to prevent the ping-pong effect. Furthermore, the timing of handoff decisions is crucial. In addition to time, other crucial decision-making variables in the handoff process include RSSI, BER, SNR, and SINR [16]. The device's speed also affects the ping-pong effect, fast-moving mobile terminals will show more ping-pong effects than terminals that are stationary or moving slowly [17].

Multiple spectrum handoffs may be necessary to allow SU continuous access to the spectrum in a CRN environment. There are two alternative outcomes, either the SU moves or becomes stationary; hence a suitable spectrum handoff mechanism is necessary. In both cases, the SU might experience a spectrum shift, necessitating multiple frequency changes and resulting in a spectrum handoff that will unavoidably occur. The likelihood of the ping-pong effect occurring will increase if the SU is moving and the system's traffic load is high at the time. However, the current strategy has not yet considered the effects of ping-pong and its consequences, according to several research [18].

III. Method of Handoff Decision

CRN has been a hot topic of discussion lately. Because CRN can increase the efficiency of spectrum use through its adaptability to its environment. In this section, we will go in-depth on a suggested two-stage fuzzy tree scheme and a method for minimizing the ping-pong effect.

A. Fuzzy Inference System (FIS) for Decision Making in Handoff

FIS is one technique that can be used in decision-making. In the field of engineering, fuzzy systems are widely used in decision-making because they are considered to have the potential to overcome these problems [19]. In addition, the fuzzy system has a relatively good computational speed, so it is very suitable for handling handoff problems in cognitive radio networks that require computational speed. The main problems with CRN, such as unpredictable conditions and possible ping-pong effects, can be explained more easily using fuzzy logic. Several existing studies have not considered much about the influence of the possible ping-pong effect by reducing the number of handoffs when the SU is in motion. Therefore, we need a method that correctly handles the problem of spectrum handoff in CRN.

B. Evaluation of the Handoff Decision Performance in Fuzzy Logic in Reduced the Ping-Pong Effect

This job studies and analyzes the use of fuzzy logic to support decision-making in reducing spectrum handoff occurrences in cognitive radio networks. The job is then modelled, validated, and evaluated using the recommended fuzzy system. The aim is to distinguish between the methodologies used in current hybrid techniques and the recommended scheme, which has been improved by shifting the point from the previous fuzzy membership function and adding a handoff threshold. The possibility of the ping-pong effect is the result of incorrect handoff decisions. Thus, reducing the number of spectrum handoffs through the right decisions can prevent the occurrence of the ping-pong effect.

C. Cognitive Radio Network Model for Fuzzy Tree Systems

The suggested hybrid fuzzy system will be examined in this part based on the following presumptions and variables [6]:

- There are two users in a cognitive radio network: the primary user (PU) and the secondary user (SU).
- It is assumed that SU can detect the existence of PU in the area.
- The FIS-1 and FIS-2 fuzzy inference systems make up the fuzzy tree system. The first system, FIS-1, was created to control and minimize PU interference by controlling the SU's strength.
- The second system, FIS-2, was created to decide how to carry out the handoff spectrum. This study aims to reduce the incidence of the ping-pong effect by making the right handoff decisions by creating a suitable threshold to reduce spectrum handoff. The inputs used for FIS-2 hold time (HT), which is used to measure channel usage by PU, power SU (P_{SU}), and Velocity SU (V_{SU}), which is the speed measured from SU.
- The SU transmit power range for Wireless Local Area Network (WLAN) is set to 30 dBm, while for Universal Mobile Telecommunications System (UMTS), it is 43 dBm.
- A simulation was run using MATLAB's fuzzy logic tools to examine the hybrid system's effectiveness [20].

This study considers five input variables significantly impacting system performance when two FLCs and five inputs exist. Fig. 1 displays these inputs along with the single output parameters.

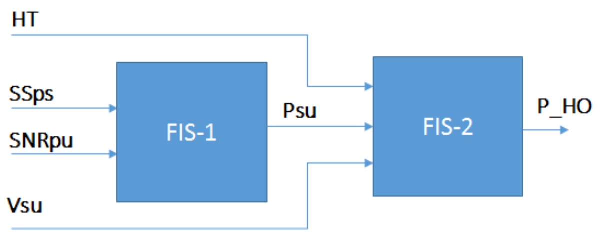


Figure 1. Fuzzy tree scheme for handoff spectrum.

Here is an explanation of the various parameters used, as shown in Fig. 1:

- SSps (Signal Strength of PU): The strength of the PU signal is measured at the SU.
- SNRpu (Signal-to-Noise Ratio of PU): The signal-to-noise ratio of the PU.
- Psu (Power of SU): Refers to the power of the SU and the output of the Fuzzy Logic Controller 1 (FIS-1)
- HT (Hold Time): Hold time refers to when PU is not using its channel.
- Vsu (SU Speed): It represents the speed of SU while in motion. Speed is a key factor that triggers spectrum handoff and may also cause a ping-pong effect.

D. Fuzzy Inference Systems-1 (FIS-1)

FIS-1 is a fuzzy inference system designed to control the power of SU (Psu) to avoid disruption to the PU, which has two inputs, SSps and SNRpu. According to the paper in [6], the FIS-1 term set is a function of f(x) and f(y), where x and y are the input and output linguistic variables, each using three linguistic variables (L, M, H). Eq. (1) displays the term set for FIS-1 in this sentence.

$$f(x) = f(y) = T(SSps) = T(SNRpu) = f(Psu)\ \{L, M, H\} \quad (1)$$

FIS-1 has the following input:

- The PU signal strength measured at SU is known as SSps.
- SNRpu stands for signal-to-noise ratio.

Table I contains the FIS-1 rules.

TABLE I. RULES FOR FIS-1 [6]

Rules	Input		Output
	SS*ps*	SNR*pu*	PSU
1	L	L	L
2	L	M	M
3	L	H	H
4	M	L	L
5	M	M	L
6	M	H	M
7	H	L	L
8	H	M	L
9	H	H	L

Fig. 2 displays the SS_{PS}, SNR_{PU}, and P_{SU} membership functions. The membership value of the fuzzy set input (μ_{x1}, μ_{x2} and μ_{x3}), where x_1, x_2 and x_3 are fuzzy system inputs, is the outcome of the fuzzification. The input value is transformed into the fuzzy set's membership value based on the membership function, as shown below.

$$\mu_{xi(L)} = \begin{cases} 1, & xi \le a \\ \frac{b-xi}{b-a}, & a < xi < b \\ 0, & xi \ge b \end{cases} \quad (2)$$

$$\mu_{xi(M)} = \begin{cases} 0, & xi \le a \text{ or } xi \ge b \\ 1 - \frac{b-xi}{b-a}, & a < xi \le b \\ \frac{c-xi}{c-b}, & b < xi < c \end{cases} \quad (3)$$

$$\mu_{xi(H)} = \begin{cases} 0, & xi \le b \\ 1 - \frac{c-xi}{c-b}, & b < xi \le c \\ 1, & xi > c \end{cases} \quad (4)$$

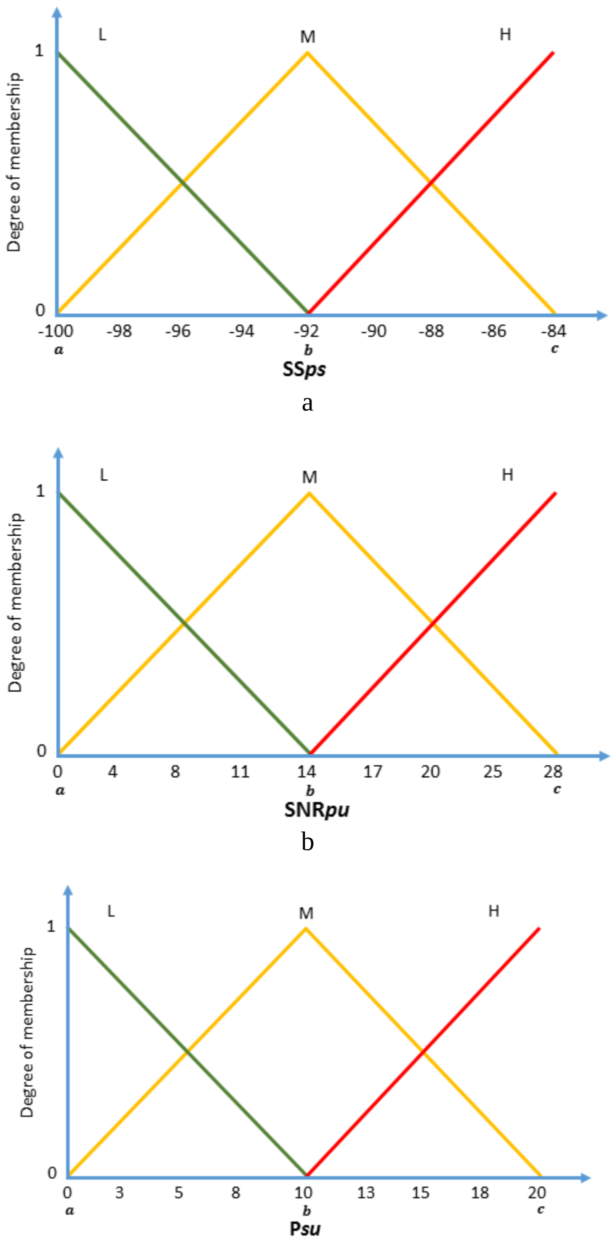


Figure 2. The SSPS, SNRPU, and PSU membership functions, respectively.

The membership function(mf) of the FIS-1 input and output is depicted in Fig. 2. The SS_{PS} membership feature is shown in Fig. 2a. It is characterized by three levels: L, M, and H. The permissible signal strength range for communication is chosen for the membership function range of -100 to -84 dBm. The MF of the signal-to-noise ratio PU is displayed in Fig. 2b (SNR_{PU}). The recommended SNR_{PU} range for data networks is 20 dB and above. For voice networks, the recommended minimum is 25 dB, while for SNR, 25 dB to 40 dB. As depicted in Fig. 2c, the P_{SU}'s membership function ranges from 0 to 20 dB. For WLAN transmit power range is set to 30 dBm, while for UMTS is 43 dBm [6].

The output linguistic variable, called P_{SU}, is determined by comparing the circumstances of two linguistic variables called SS_{PS} and SNR_{PU}, which form the basis of the fuzzy rule base for FIS-1. For instance, in Regulation No. 1, Low SSps (L) indicates that the PU and SU are far apart; Second, Low SNRpu (L) indicates that the PSU does not require an increase and that the Psu value is therefore judged to be Low (L). In rule No. 3, the SSps value is L, and the SNRpu value is H, indicating a significant separation between PU and SU and an estimated PSU value of H. According to Rule No. 9, if SS_{PS} is H, SNR_{PU} is in an H state, PU and SU are separated by L, and PSU is in an L state if SSPS is H and SNRPU is in an L state [6].

E. Fuzzy Inference Systems-2 (FIS-2)

Based on the following inputs, the second Fuzzy inference system, FIS-2, is intended to conduct spectrum handoff (HO):

- The Hold Time channel (HT) is connected to the period when the PU does not use its channel.
- VSU: This variable represents the SU's movement speed. Speed is one of the leading causes of spectrum handoff and potential Ping-Pong effect issues.
- PSU: is the power source for the secondary user, which is controlled and monitored by FIS-1 and used as input to FIS-2.

Table II displays the FIS-2 rules.

TABLE II. FIS-2 ESSENTIAL RULES [6]

Rules	Input			Output
	HT	Psu	Vsu	P_HO
1	L	L	L	M
2	L	L	M	H
3	L	L	H	VH
4	L	M	L	M
5	L	M	M	H
6	L	M	H	H
7	L	H	L	H
8	L	H	M	H
9	L	H	H	VH
10	M	L	L	M
11	M	L	M	M
12	M	L	H	H
13	M	M	L	L
14	M	M	M	L
15	M	M	H	H
16	M	H	L	VL
17	M	H	M	L
18	M	H	H	M
19	H	L	L	M
20	H	L	M	H
21	H	L	H	VH
22	H	M	L	VL
23	H	M	M	L
24	H	M	H	M
25	H	H	L	VL
26	H	H	M	L
27	H	H	H	M

The term assigned to FIS-2 depends on the variables f(x) and f(y), where x is the input and y is the output for the respective linguistic variables. Eqs. (5) and (6) are linguistic variables for inputs and outputs in FIS-2.

$$f(x) = f(HT) = f(Psu) = f(Vsu) = \{L, M, H\} \tag{5}$$

$$f(Y) = f(P\_HO) = \{"Verylow", "Low", "Medium", "High", "Veryhigh"\} \tag{6}$$

The membership functions for the linguistic input variables are shown in Fig. 3. Fig. 3a depicts the membership function for the Holdtime (HT), or the time when the channel is free and not used by PU, during which SU may use the same track for data transmission. The output of FIS-1 is Fig. 3b, which depicts the PSU membership function. The third input's membership function, the VSU speed, is displayed in Fig. 3c. The SU speed in this section is set to 100 km/h since this range encompasses the highest speeds that are legal in densely populated urban areas (40 to 50 km/h), on arterial roads (80 km/h), and highways (up to 100 to 120 km/h). The cell size is typically smaller in urban areas and cities, which increases the likelihood of a ping-pong effect.

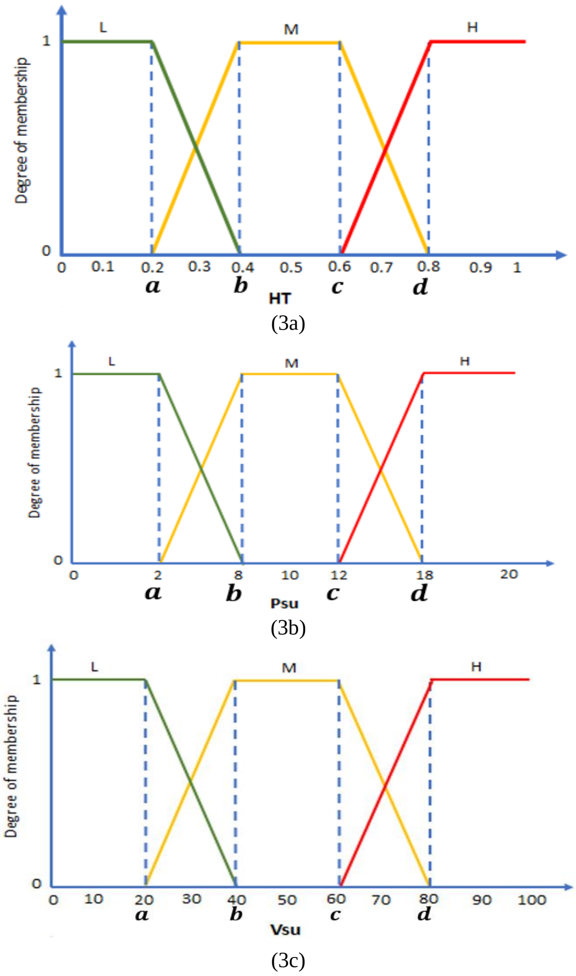


Figure 3. The HT, P_{SU}, and V_{SU} roles as members of FIS-2.

Lowering the handoff rate will lessen the ping-pong effect. Fig. 4 depicts the MF for the P_HO, or potential spectrum handoff, of the FIS-2 output. The definition of the MF for P_HO in terms of five linguistic variables is shown in Eq. (6).

Fig. 3 displays the membership functions for HT, P*su*, and V*su*. The membership value of the fuzzy set input (μ_{x1},

μ_{x2} and μ_{x3}), where x_1, x_1 and x_1 are fuzzy system inputs, is the outcome of fuzzification. The input value is transformed into the fuzzy set's membership value based on the membership function, as shown below.

$$\mu_{xi(L)} = \begin{cases} 1, & xi \le a \\ \frac{b-xi}{b-a}, & a < xi < b \\ 0, & xi \ge b \end{cases} \quad (7)$$

$$\mu_{xi(M)} = \begin{cases} 0, & xi \le a \text{ or } xi \ge d \\ 1 - \frac{b-xi}{b-a}, & a < xi < b \\ 1, & xi \ge b \text{ or } xi \le c \\ \frac{d-xi}{d-c}, & c < xi < d \end{cases} \quad (8)$$

$$\mu_{xi(H)} = \begin{cases} 0, & xi \le c \\ 1 - \frac{d-xi}{d-c}, & c < xi < d \\ 1, & xi \ge d \end{cases} \quad (9)$$

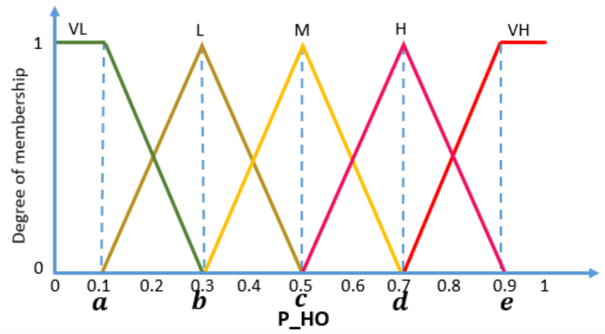


Figure 4. The P_HO membership function.

From the observation, it was found that if a spectrum handoff occurs, the input's status is considered. In regulation number 1, for instance, the HT, P_{SU}, and V states are all L, indicating that the SU power and speed are both low, but the HT is still lacking. Because of this, there is a high likelihood of PU development and a moderate chance that a handoff spectrum will occur. Rule number 2's SU speed is high due to an anticipated high likelihood of spectrum handoff, like Rule number 1's. The condition of P_HO is VH because there is a strong possibility that PU will appear and occupy the channel, like regulation number 9 when HT is L and P_{SU} and V are both H. P_{SU} is H, HT is M, and V_{SU} is L in regulation number 16. Due to the low probability of PU and the slow speed of SU, P_HO is VL, indicating that there is little need for a handoff spectrum. P_HO is M in regulation number 27, and all H inputs are high. Maintaining the potential for medium spectrum handoff is a sensible decision, as the SU can be aided by the channel's high hold time (HT) and high transmit power (P_{SU}) [6]. The PU and SU distance may be high even if SU operates at a fast speed, and the power may also be increased. However, because HT is also high, the channel is largely vacant despite the possibility of Ping-pong.

IV. Results of the Simulation and Discussion

Results from simulations of current systems and fuzzy tree systems are presented in this section. The criteria and situations listed in Section III evaluate each scenario. Results are explained, analyzed, and compared afterward.

A. Results of Fuzzy Tree System Analysis

The testing results of a fuzzy tree-based fuzzy inference system that attempts to lessen the frequency of spectrum handoff to diminish the likelihood of a ping-pong effect are shown in Fig. 5 below. Fig. 5 displays the results of the FIS-1 simulation. This demonstrates how SNRPU and SSPS relate to the PSU value. It is obvious that as SSPS and SNRPU rise in value, PSU falls in value. This tendency is warranted because as PU signal strength and signal-to-noise ratio increase, the likelihood that the PU channel will be used increases. The SU power level must remain low while the PU is in the run.

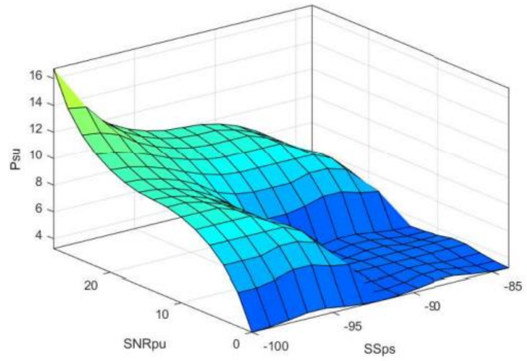
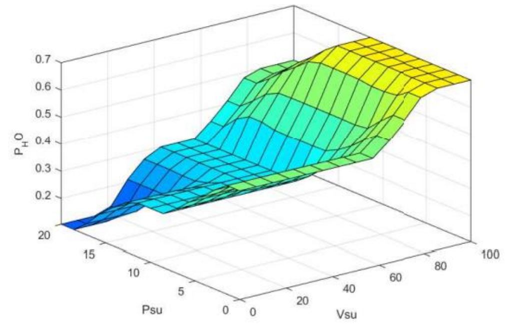
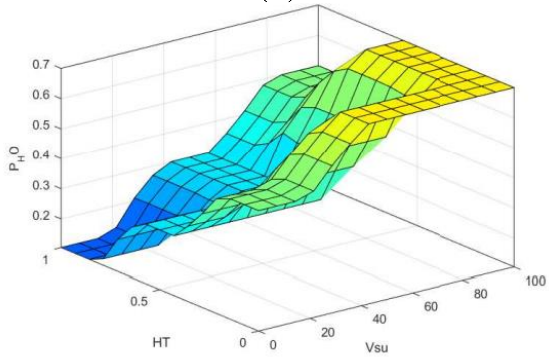


Figure 5. Simulated FIS-1 Results [6].



(6a)



(6b)

Figure 6. Probabilities of spectrum handoff related to input from FIS-2 [6].

The results of the FIS-2 simulation are shown in Fig. 6. If the PSU in Fig. 6a is constant and the VSU speed of the SU is at the lowest point, then the P_HO value is also at the lowest. Similarly, when the VSU value rises, the P_HO probability also rises, but when the PSU is at its highest, the P_HO value does not suddenly rise. This is crucial because while the SU is moving quickly, it is more likely to estimate the need for a spectrum handoff despite receiving a strong signal from the base station that serves it. As a result, moving into adjacent cell boundaries may result in a spectrum handoff. Consequently, increasing the system's processing load and such circumstances may cause a ping-pong effect.

The potential handoff spectrum concerning HT and VSU are depicted in Fig. 6b. Fig. 6b demonstrates that when the probability of HT is highest, the probability of spectrum handoff is lowest; in other words, a high likelihood of HT indicates that the probability of PU occupying the channel is low, resulting in a high channel hold time, which in turn results in a low requirement for spectrum handoff and leaves the channel open for SU. The same picture demonstrates that when SU speed increases, the chance of the handoff spectrum does not necessarily rise; instead, it is controlled appropriately, minimizing the likelihood of the ping-pong effect at high speeds.

V. Analysis and Discussion

Results from a comparison of spectrum handoff reduction strategies are shown below. To lessen the ping-pong effect by narrowing the handoff spectrum, the fuzzy tree system's graphical analysis is depicted in Fig. 7.

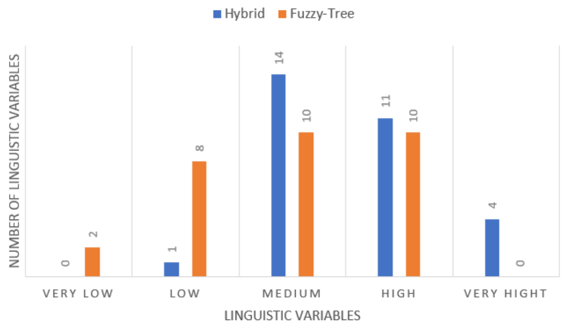


Figure 7. Comparison of the proposed fuzzy system model (Fuzzy-Tree) with the current system model (Hybrid).

The fuzzy tree system aims to reduce spectrum handoff and minimize the ping-pong effect. The handoff spectrum probability system is designed using five linguistic variables, namely very low (VL), low (L), moderate (M), high (H), and very high (VH). Of the 30 tests carried out, it was found that for the hybrid model, the number of VL was 0 (0%), then for L, it was 1 (3%), then for the number of M, it was 14 (47%), then for the number of H it was 11 (37%) and for the number of VH as much as 4 (13%). Whereas for the fuzzy tree model, the number of VL is 2 (7%), then the number of L is 8 (27%), while the number of M and H is 10 (33%) respectively, and the number of VH is 0 (0%). If observed, the spectrum handoff probability increases with increasing SU speed. In the fuzzy tree model, the spectrum handoff probability decreases drastically as the number of VH and H decreases. This reduction is based on improving the membership function in the fuzzy system to result in the right spectrum handoff decision, and the ping-pong effect can be automatically minimal. As the SU speed increases, the ping-pong effect is more likely to occur. Although the increase in speed encourages the occurrence of spectrum handoff, this process must be intelligently managed based on the input applied through the design of the membership function in the right fuzzy system. The test results show that the number of handoff spectrums has decreased by up to 43% compared to other methods, which are only 60%. There is a difference in handoff reduction of 16.67% from the previous method. Thus, the ping-pong effect can be minimized with the right handoff decisions. Thus, the aim of reducing the ping-ping effect can be implemented.

Based on the fuzzy output value, a final judgment is made on whether to execute the handoff [21]. If the fuzzy output value is more than 0.5, handoff will occur. However, when the fuzzy output value is less than or equal to 0.5, the SU continues to be connected to the existing channel, as illustrated in Fig. 8.

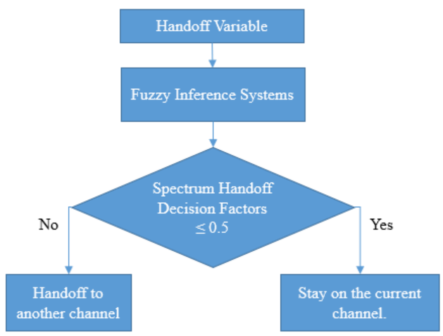


Figure 8. The process of determining the spectrum handoff.

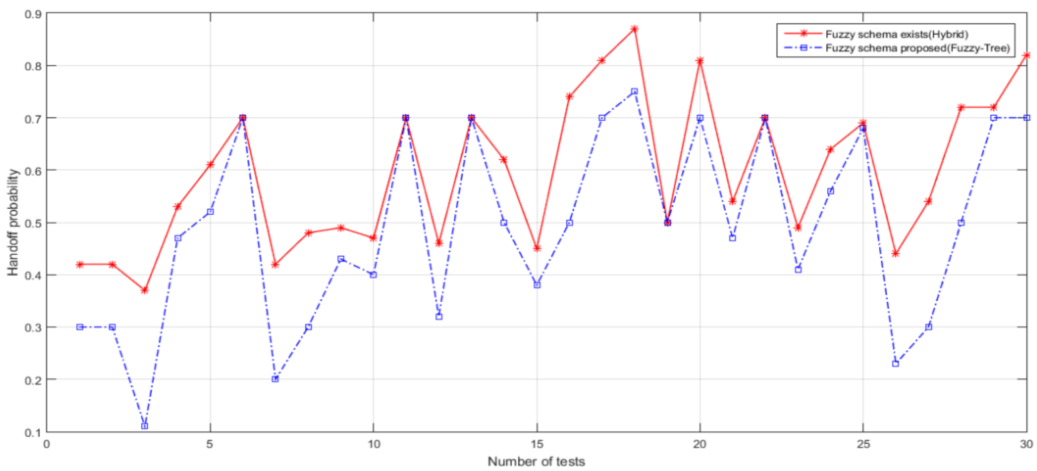


Figure 9. Shows a comparison between the proposed fuzzy tree system model and the current system model.

The fuzzy tree system model with the proposed enhancements to the membership function is compared to the existing hybrid system model in Fig. 9 for the spectrum handoff.

Next, we focus on how many handoffs are initiated during simulations. From testing 30 times, our proposed model is detected to initiate handoffs 13 times, or 43%, while existing methods are detected to initiate handoffs 18 times, or 60%. Thus, there is a reduction of 16.67% from the previous method. If measured in terms of the percentage of handoffs, the calculation below is obtained:

$$Hybrid\ Method = \frac{18}{30} \times 100 = 60\ \%$$

$$Fuzzy\ Tree\ Method = \frac{13}{30} \times 100 = 43\ \%$$

$$Reduction = \frac{(18-13)}{30} \times 100 = 16.67\ \%$$

The findings show that when compared to the current hybrid system, the proposed Fuzzy Tree system minimizes the amount of spectrum handoff. It can be concluded that if the spectrum handoff frequency can be lowered correctly, then the occurrence of the ping-pong effect can be reduced.

In this section, we analyze the work that has already been done using the hybrid system that was previously designed. Then, we conduct testing simultaneously with the proposed Fuzzy Tree system. The test results found that the proposed fuzzy system has better performance, characterized by decreasing handoffs compared to previous fuzzy systems. The decrease in the number of handoffs indirectly minimizes the ping-pong effect. The technique that we propose is based on the use of fuzzy logic. The use of fuzzy logic helps create a rule base with the best decision-making capabilities and can be used or changed according to changes in wireless environmental conditions.

VI. Conclusion

Spectrum is a limited resource, so it must be used effectively. The fixed spectrum allocation method currently in operation may not sustain the growth in the network access users, which continues to increase over time. Thus, there is a need for a dynamic spectrum allocation strategy that allows the spectrum to be shared with other users. Spectrum sharing serves as the foundation for the idea of cognitive radio. The Cognitive Radio Network must be able to adapt and learn from its environment to help solve the spectrum scarcity problem. However, issues like the ping-pong effect could appear when switching between spectrums. When a user moves quickly, this issue might have severe repercussions and raise the network's processing demand. This research aims to reduce spectrum handoff by making the right decisions in the cognitive radio network, which will indirectly minimize the possibility of the ping-pong effect. It is known that fuzzy logic is a method that can be used to make decisions in uncertain situations like CRN. However, a better method can be achieved by adjusting the form of its membership function to support the right handoff decision. A fuzzy tree system based on fuzzy logic for cognitive radio networks has been proposed, considering many similar studies. This system will improve performance in making the right spectrum handoff decisions and will indirectly reduce the possibility of ping-pong. The simulation results of the proposed system show effective spectrum handoffs and a significant reduction in the number of handoffs. Test results show that the number of detected spectrum handoffs has decreased or is only 43% compared to other methods, which is still relatively high at 60% from the range of tests conducted. This results in a decrease of 16.67% from the previous method. With the right handoff decision, the possibility of the ping-pong effect can be minimized.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

SDR develops methodologies, conducts thorough simulations, and produces papers. SS and IWM clarified the problem formulation and validated and assessed the findings. All authors have approved the final draft.

Acknowledgment

This work was supported by RTA 2021, Research Directorate at Universitas Gadjah Mada.

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