Improving Performance of Fuzzy-Based Handoff for Spectrum Utilization in Cognitive Radio Network Using Particle Swarm Optimization

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***Abstract*—Cognitive Radio Network (CRN) has received attention as it is considered a potential method to solve the issue of limited and rare spectrum resources for improving the capacity of wireless communication. One of the fundamental requirements of dynamic spectrum access in CRN is the handoff decision made by the Secondary User (SU) when the Primary User (PU) uses his channel. Previously, fuzzy algorithm was proposed to solve the handoff problem in CRN by several researchers. In this study together, we propose to use Particle Swarm Optimization (PSO) in optimizing the Membership Function (MF) to improve the performance of fuzzy-based handoffs to reduce the occurrence of incorrect handoffs. The proposed scheme consists of two parts that are Fuzzy Logic Controllers-1 (FLC-1) and Fuzzy Logic Controllers-2 (FLC-2). The first part (FLC-1) is used to control SU power and to avoid interference with PU, while part 2 (FLC-2) is used to support accurate spectrum handoff decisions. Based on the simulation results, it shows that the number of handoff spectra has decreased by 30% for all MF optimization on FLC-2 (MFFLC-2), then 50% for MF optimization on Psu only (MFPsu), and 70% for MF on fuzzy, which does not optimize using PSO. Thus, the optimization of MF on the fuzzy system can improve the performance of the fuzzy-based handoff scheme at CRN by precisely reducing the number of handoffs.**

***Keywords*—cognitive radio network, handoff, particle swarm optimization, membership function, fuzzy logic controllers-1, fuzzy logic controllers-2**

I. INTRODUCTION

In current years, Cognitive Radio Network (CRN) has acquired particular attention as it is considered a potential method to solve problems in spectrum scarcity [1]. CRN offers dynamic spectrum allocation techniques to help prevent interference and quickly respond to spectrum availability. A cognitive radio is a type of radio that adjusts its communication settings founded on its surroundings [2]. Several studies have shown that the available frequency band is mostly congested with high traffic and all these conditions create a spectrum scarcity problem that is anticipated to happen in the future [3, 4].

In a CRN, individuals are classified as either Primary User (PU) or Secondary User (SU). PU has sole rights to the spectrum and takes precedence over SU. On the different, SU are unlicensed users who access the network opportunistically, so SU need to be able to sense the band's availability and choose a band not used by PU [4, 5]. Spectrum sensing requires a capability to detect unoccupied of Radio Frequency (RF) by PU [6]. The spectrum decision function aids SU in selecting a spectrum gap for their transmission through network support or independently. The next step after choosing an empty channel is to execute the spectrum handoff. If not operated correctly, changing channels or bands for spectrum handoff can cause unintended problems such as the ping-pong effect [7]. In Ref. [6], the ping-pong effect can be seen as a research gap; this can be based on several related studies, where the ping-pong effect needs to be considered more in making spectrum handoff decisions.

The emergence of PU to access its licensed spectrum when SU is using it is an issue that arises in spectrum mobility. This condition requires SU to vacate the channel it is using immediately. One of the four crucial functions performed by CRN, which attempts to keep SU communications operating ongoing, is spectrum mobility [4]. Spectrum handoff and connection management are the two procedures that makeup spectrum mobility. The continual process of moving data transmissions from the existing channel to a new channel is comprehended as spectrum handoff. While connection management helps maintain connections during the handoff process [8]. Therefore, an appropriate mechanism must be applied to find other suitable channels to support the next transmission of SU data [9, 10].

Spectrum handoff can be classified into reactive and proactive spectrum handoff [11, 12]. Handoff is crucial when the cell size is tiny compared to the Mobile Station's (MS) typical speed [13, 14]. The degree of handoff may be inversely related to cell size [13]. Due to the existing

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network's heterogeneity and cell size, the spectrum handoff procedure in CRN is more complicated and demands greater accuracy [6].

The existence of a power readjustment process can cause signal variations, and this condition can increase the number of handoffs in obtaining another spectrum. The ping-pong effect refers to this repetitive and pointless handoff. The network needs to make some accurate and efficient handoff decisions to prevent the ping-pong effect. In addition, the timing for making handoff decisions is critical. Apart from time, several important decision factors in the handoff process are Signal to Noise Ratio (SNR), Signal to Interference and Noise Ratio (SINR), Received Signal Strength Indicator (RSSI), Bit Error Rate (BER), etc. [15]. The ping-pong effect also depends on the device's speed because mobile terminals that move very fast produce more ping-pong effects than mobile terminals that move slower or stay still [16].

In a CRN environment, it may be necessary to repeatedly handoff the spectrum to provide continuous access to the SU in its transmission [17]. Therefore, a proper spectrum handoff mechanism is needed because two scenarios will occur wherein the SU may move or become stationary. In both cases, SU can encounter a spectrum shift, necessitating many changes to its operating frequency to complete a spectrum handoff. There will be a greater likelihood of a ping-pong impact if the SU is moving, and the system traffic load is high at that moment [6]. However, many current methodologies have yet to consider the ping-pong effect and its effects in various investigations [18].

When the SU changes its operating frequency, it does so due to many factors, including the use of the channel by the PU and the PU unexpected arrival. In contrast, the channel is already in use by the SU, a decline in the quality of the channel being used by the SU, interference with the PU transmission from the SU, and the SU moving outside of its connection area. Thus, there should be as little delay as possible during the spectrum handoff [19, 20].

Fuzzy logic is highly suitable for the handoff spectrum in CRN, which are uncertain due to its ability to handle the ambiguity of information. When the received information is incomplete and vague, the use of fuzzy logic can assist in modeling the problem [6].

Fuzzy logic extends the principles of Boolean logic to account for imprecision and uncertainty. The approach is rooted in the mathematical theory of fuzzy sets and is a component of the larger domain of soft computing, which encompasses genetic algorithms and neural networks [21–23]. In recent years, there have been numerous suggestions for utilizing soft computing in various fields [21]. Fuzzy Logic Controllers (FLC) is rooted in the principles of fuzzy logic [10]. In the FLC, linguistic control strategies are transformed into automatic control strategies. The natural language text of this rule-based controller is converted into fuzzy logic. Fuzzification, fuzzy inference, and defuzzification are the three main components of the FLC. Normalized values from each input and output are translated to fuzzy sets using a Membership Function (MF) throughout the fuzzification process. MF forms can vary; generally, MF structures can be Gaussian, triangular, trapezoidal, etc. The fuzzification step creates a fuzzy division of every input or output area. This condition has yet to have a definite solution in finding the optimal form of MF, which makes it possible to get the best defuzzification results. Particle Swarm Optimization (PSO) can resolve the problem of optimizing the fuzzy MF. Kennedy and Eberhart first proposed PSO, an evolutionary computing technique, in 1995 [24]. The PSO method mimics the collective behavior of biological groups, like birds, to locate the optimal or nearly optimal solution to a multi-variable problem within a continuous search space [25].

To determine the best settings for each input process in FLC, we only considered the trapezoidal and shoulder MF together with the PSO algorithm in this study. The PSO algorithm is used to improve the fuzzy MF to overcome the spectrum handoff problem in CRN.

The main contribution of this work is to improve the performance of the Fuzzy system by adjusting the MF using the PSO algorithm to support Fuzzy-based handoff decisions on CRN so that the handoff process executed by SU can be carried out correctly. In addition, this study compares a model whose MF is not regulated using PSO with a model whose MF has been adjusted using PSO to see how many handoffs occur.

The remaining sections are classified as follows: Section II is related work that covers fuzzy MF, the ping-pong phenomenon, and how fuzzy logic can be utilized for spectrum handoff decision-making. It also covers overviews of MF, and linguistic variables. In Section III, we discussed the PSO algorithm. In Section IV, we explain the proposed handoff scheme. In Section V, we present and discuss the simulation results. Finally, the findings and conclusion are described in Section VI.

II. Literature Review

In this section, we briefly discuss the state-of-the-art handling of spectrum handoff based on fuzzy logic in CRN. A fuzzy logic-based approach is suggested in [26] to deal with spectrum handoff. The presented technique efficiently handles spectrum handoff decisions if SU interferes with PU. The system is made to regulate the strength of the SU, the intensity of the interference, and the separation between the SU and PU. Fuzzy logic is quite compelling when it comes to fading channels, route loss, and the variety of the wireless environment [17]. As mentioned in [6, 20, 21], fuzzy sets and inference rules in fuzzy logic stand created with humane comprehension in mind, ensuring an efficient solution to a problem.

Ehiagwina and Monikang [26] utilizes the particle swarm optimization algorithm to determine the optimal fuzzy relation matrix for a novel fuzzy reasoning model aimed at modeling. The simulation outcomes demonstrate that a proficient fuzzy model for intricate systems can be achieved without expert input. MutaherBa-Alwi [27] also introduces a repetitive procedure for changing MFs distributions for the fuzzy inference system (FIS), even though the process takes time and is subjective. To eliminate subjectivity in the definition of MFs, Mamdani *et al.* [28] uses expert opinion aggregation to determine MFs from the FIS, the outcome largely depending on the subjective interpretation of each expert of various linguistic terms.

However, various computational techniques have been applied to the determination and tweaking of MF. One method employs a clustering algorithm to categorize raw data into clusters, as described in [12]. To ascertain the MF of the formed clusters, an artificial neural network (ANN) is used. The algorithm needs a large amount of data for this strategy to work. Wang *et al.* [13] also utilizes a Genetic Algorithm (GA) to optimize a set of pre-defined MFs in a fuzzy system to control a helicopter. Additionally, GA needs a large amount of data to perform effective searches, and understanding the underlying mechanism is crucial for encoding data into GA chromosomes. The MF of the New Fuzzy Reasoning Model (NFRM) used to model nonlinear plants is optimized in this article using particle swarm optimization. The model's accuracy is evaluated against the NFRM made by a professional using non-optimized MF.

The MF plays a critical role in a fuzzy logic-based decision-making system. The MF is the core of fuzzy logic-based decision design [28]. Determining the MF is the key to fuzzy logic because the design of the MF greatly affects the consistency, accuracy, and quality of the decisions made by the system [29]. In a Fuzzy Inference System (FIS), each input variable is divided into overlapping vague categories, such as "Large (L)," "Medium (M)," "Small (S)," etc., covering the entire range (or universe of discourse) of the input. The input value can belong to more than one partition because these partitions overlap, as described by the MF that follows [30]. For Mamdani and NFRM fuzzy models, the output is divided into fuzzy categories like the input. Meanwhile, TSK fuzzy models use a linear connection among input and output variables to express the result, as described in [31].

From the description above, it is clear that MF is very influential on fuzzy systems [32, 33], Which suggests that the choice and definition of the MF parameters in the fuzzy set influence the ability of the fuzzy inference system. For example, larger partitions and increased uncertainty lead to more rules and slower replies because more computation is required to complete the rules before output is generated [30]. Therefore, the effectiveness of a Fuzzy Inference System is affected by factors such as the total of partitions and the definition of the related MF.

Despite the significance of an MF, there is no practical way to establish the type, quantity, or variety of MF. Usually, technical evaluation, intuition, necessary application, or designer expertise are used to make a subjective determination of MF. In contrast to Gaussian-shaped MFs, which appear more suitable for function approximators, triangular MFs are frequently employed for general control applications [30].

III. Particle Swarm Optimization (PSO)

PSO is an optimization algorithm that employs a randomly generated set of solutions (particles) to examine the find area. The position of each particle denotes a candidate solution to the optimization problem, and its quality is evaluated through a price function specific to the situation. All particles in the foundation area move, and every particle's motion is guided by its best-discovered solution or its best location. This work employs a single-swarm PSO algorithm, in which all particles are connected to communicate, and their movements may be influenced by the best solution searching so far by the swarm, also known as the global best. The location vector $x \in \mathbb{R}^N$ and the velocity vector $v \in \mathbb{R}^N$ in real number space, where N is the size of the find area, respectively, indicate the position and velocity of every particle [21]. Each particle's position and velocity are updated as follows:

$$v_k(t+1) = wv_k(t) + c1r1\big(p_k(t) - x_k(t)\big) + c2r2\big(g(t) - x_k(t)\big) \quad (1)$$

$$x_k(t+1) = x_k(t) + v_k(t+1) \quad (2)$$

The particle index is represented by k, where $1 \le k \le N$ and N is the swarm size. t stands for the time step, $x_k(t)$ and $v_k(t)$ are the position and velocity of particle k, respectively, $p_k(t)$ is particle k's personal best position at time t, and $g(t)$ is the global best position of all particles in the swarm at time t. $r1$ and $r2$ are random numbers with a uniform distribution between 0 and 1, w is the inertia weight, and $c1$ and $c2$ are cognitive coefficients [21]. PSO involves a repeating cycle where each particle's initial position and velocity are randomly assigned. The cost function for each particle is evaluated to find the best location in the swarm. The particle's position and velocity are then adjusted using Eqs. (1) and (2), and the particle's best location (pbest), as well as the swarm's best location (gbest), are updated, if necessary, based on the particle's cost function. The updated pbest and gbest values shape the interaction between particles after each iteration, until the search process concludes [17]. The iteration stops when the termination criteria are met. The algorithm terminates when the defined criteria are satisfied, and the final global best position is the solution found by PSO.

IV. Fuzzy Schematic-Based Spectrum Handoff

In this study, we used the concept of merging two FLCs, called a fuzzy tree scheme, consisting of FLC-1 and FLC-2, as shown in Fig. 1. To illustrate the proposed PSO algorithm, we use an FLC with three MFs (left shoulder, trapezoid and right shoulder) for each input in FLC-2. An illustration of the fuzzy partition for each piece of information on FLC-2 can be seen in Fig. 2. The MF parameter on FLC-1 is not adjusted using PSO. The form of MF is adjusted to that found in previous studies [8]. We want to see the impact when one of the FLCs, in this case, FLC-2, has its MF set using PSO. For PSO simplification, it is assumed that the MF linguistic limit parameters of aL, bL, bM, cM, bH, and cH for each input in FLC-2 are fixed. Thus, four linguistic boundary parameters of the fuzzy partition of FLC-2 will be optimized using the PSO algorithm as shown in Eq. (3).

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 (FLC-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.

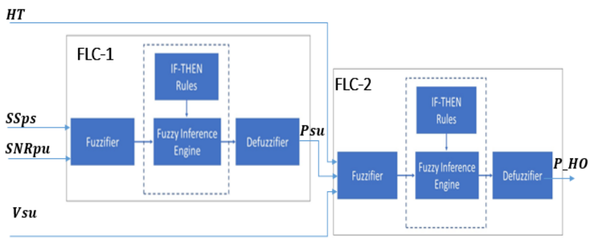


Figure 1. A fuzzy tree scheme consisting of a combination of FLC-1 and FLC-2.

The following provides the general particle's structure as shown in Eq. (3).

$$\mathrm{MF}_{opt} = |\ cL\ aM\ dM\ aH\ | \tag{3}$$

where MF*opt* is an optimized MF, while *cL*, *aM*, *dM*, and *aH* are linguistic limits on MFs regulated using PSO.

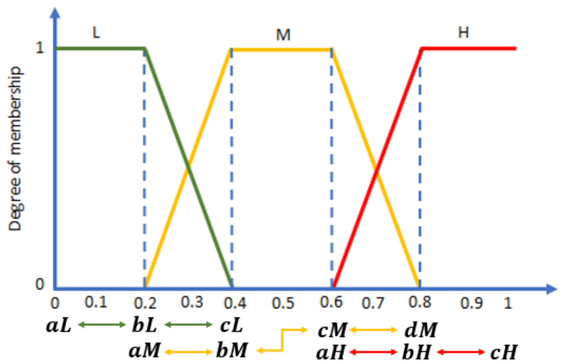


Figure 2. Illustration of trapezoidal and shoulder MFs.

So based on Fig. 2, the parameters to be optimized must meet the conditions as shown in Eq. (4).

$$\begin{aligned} aM_{opt} &= bL \le aM < cL \\ cL_{opt} &= aM < cL \le bM \\ aH_{opt} &= cM \le aH < dM \\ dM_{opt} &= aH < dM \le bH \end{aligned} \tag{4}$$

For *aMopt*, *cLopt*, *aHopt*, and *dMopt* in Eq. (4) is the linguistic limit on the MF that will be regulated using PSO based on the defined function rule limits, as shown in Fig. 2.

Every iteration carried out by PSO must be evaluated using Eq. (4), as shown in Fig. 2.

The fuzzy input MF FLC-2 (HT, V_su, P_su) to be optimized is the shoulder and trapezoidal function, each with 3 MF, namely L, M, and H. The steps in optimizing the fuzzy MF with PSO are performed in stages, as shown in Fig. 3.

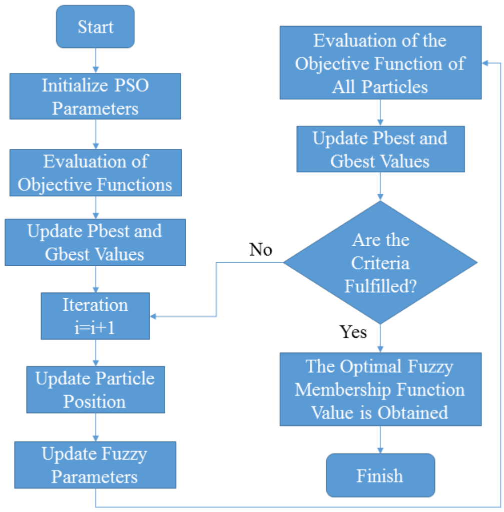


Figure 3. Step optimization of the MF using PSO.

V. Results and Discussion

We evaluated the performance of the proposed scheme by using Matlab, which is a meta-paradigm numerical computing environment using fourth-generation programming language [34], and the final decision to perform handoff was made based on the fuzzy logic output value. If the output value exceeds 0.5, handoff occurs; otherwise, the connection stays on the current channel [7]. The simulation results from the fuzzy-based method and the PSO that were used to modify the trapezoidal and shoulder MF in FLC-2 are shown in this section. The aim is to support accurate spectrum handoff decisions in CRN. In this work, we will optimize the MF of FLC-2. The decision to perform spectrum handoff is based on the following inputs [6]:

- *HT*: It's a Hold Time channel related to the duration where PU does not use its channel.
- V_{su}: This variable indicates the speed of SU when moving. Speed is a key factor that triggers spectrum handoff.
- P_{su}: As an input to FLC-2, FLC-1 regulates and monitors the SU strength.

The FLC-2 system in the simulation uses five linguistic variables to describe the handoff probability [6]. Fig. 4 serves as an example process of determining the spectrum handoff.

The findings show that the proposed scheme could reduce the amount of spectrum handoffs compared to a fuzzy system whose MF needs to be optimized. As a result, if the amount of spectrum handoffs can be reduced appropriately, choosing to resolve the spectrum handoffs more precisely may minimize the impact of Ping-pong.

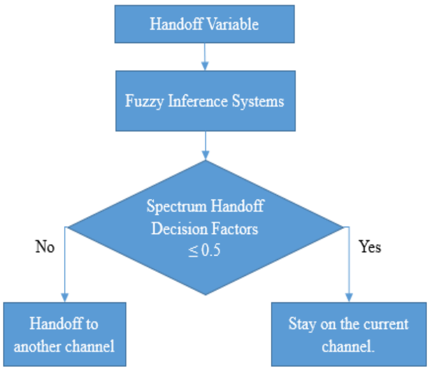


Figure 4. The process of determining the handoff.

In this section, we evaluate the performance of the proposed scheme with the existing system. We compared the performance with the fuzzy system scheme in the previous study [6], then the evaluation results were compared with the proposed scheme. This research used two scenarios to measure the performance after optimizing MF in the fuzzy system. In the first scenario, we tested one of the optimized MFs, P_su, as shown in Fig. 4. The selection of this parameter is based on its impact on the received signal strength and is the output from FLC-1. The proposed system model successfully reduced spectrum handoff compared to the previous method, thus reducing the risk of the Ping-pong effect from improper handoff. Fig. 5 shows the handoff measurement results in the optimization of membership function Psu (MFPsu). Using the threshold values described in Fig. 4, some points appear to be lower compared to the fuzzy system without optimization.

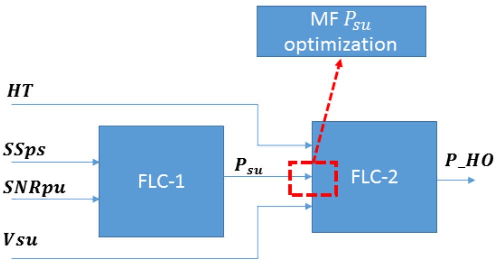


Figure 5. Optimization scheme on MFP_{su}.

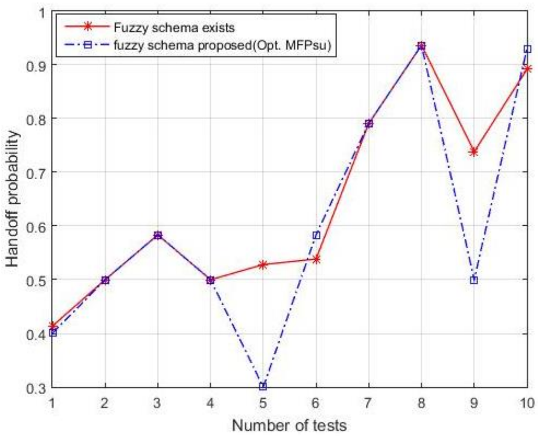


Figure 6. Graph of handoff measurement results on MFP_{su} optimization.

For the second scenario, we optimized the MF for all variables in FLC-2, as shown in Fig. 6. Then we tested to compare the results obtained with the unoptimized fuzzy model. From the tests conducted, it was found that the performance of the optimized MF fuzzy model had a significant impact on reducing the number of handoffs. As shown in Fig. 7, using threshold values as described in Fig. 4 shows that some points have lower handoff values compared to the unoptimized fuzzy model. Thus, the optimization performed on the MF fuzzy greatly impacts the spectrum handoff decision.

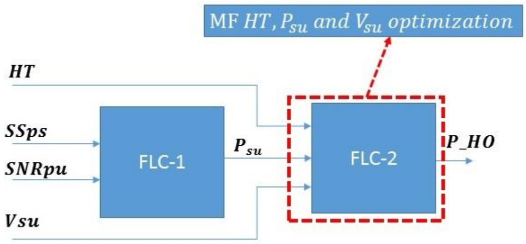


Figure 7. Optimization scheme on $MFFLC-2$.

Fig. 8 shows a comparison graph of the fuzzy model that is not adjusted using PSO with the MFFLC-2 model that has been adjusted using PSO.

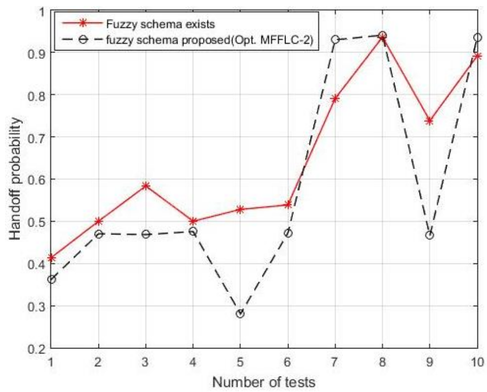


Figure 8. Graph of handoff measurement results on $\mathrm{MFFLC}-2$ optimization.

Fig. 9 shows the overall graph of the fuzzy model that has been tested as a comparison between the existing fuzzy model, MFPsu, and MFFLC-2.

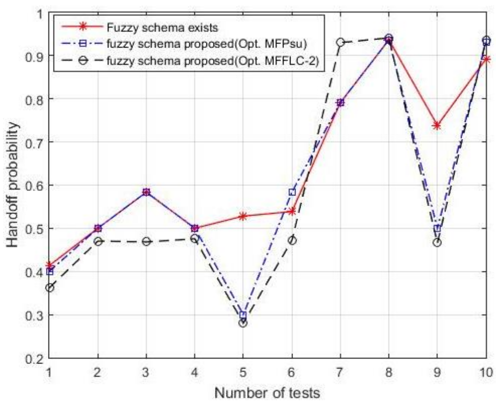


Figure 9 Graph of handoff measurement results on $\mathrm{Fuzzy}, \mathrm{MFP}_{su}$ and $\mathrm{MFFLC}-2$ optimization.

The comparison results between unoptimized fuzzy, MFPsu, and MFFLC-2 are shown in Table I, where a decrease in the number of handoffs of 70%, 50%, and 30% was observed from each of the ten tests. If measured in percentage handoffs, the following calculation is obtained:

$$Fuzzy\ Schema\ Existing = \frac{7}{10} \times 100\% = 30\%$$

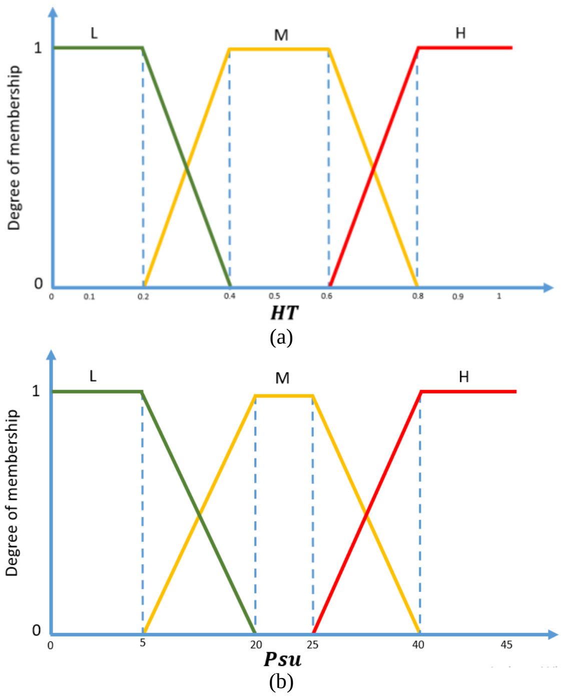
$$Fuzzy\ Schema\ Proposed\ (MFPsu) = \frac{5}{10} \times 100\% = 50\%$$

$$Fuzzy\ Schema\ Proposed\ (MFFLC-2) = \frac{3}{10} \times 100\% = 70\%$$

The findings show that when compared with a fuzzy system where the MF is not optimized, the proposed Fuzzy system minimizes the number of spectrum handoffs, both optimization of the MF on the Psu variable only and on the entire MF on the FLC-2 variable. Properly reducing the number of handoffs can prevent disruption to PU.

TABLE I. SHOWING COMPARISON BETWEEN UNOPTIMIZED MF FUZZY, OPT. MFPSU AND OPT. MFFLC-2

Fuzzy Schema Existing		**Fuzzy Schema Proposed (MFPsu)**		**Fuzzy Schema Proposed (MFFLC – 2)**	
P_HO	**Status**	***P_HO***	**Status**	***P_HO***	**Status**
0.41	No	0.40	No	0.36	No
0.50	No	0.50	No	0.47	No
0.58	Handoff	0.58	Handoff	0.46	No
0.50	No	0.50	No	0.47	No
0.52	Handoff	0.30	No	0.28	No
0.53	Handoff	0.58	Handoff	0.47	No
0.79	Handoff	0.79	Handoff	0.93	Handoff
0.94	Handoff	0.94	Handoff	0.94	Handoff
0.74	Handoff	0.50	No	0.46	No
0.89	Handoff	0.93	Handoff	0.93	Handoff
Number of Handoffs	**7**		**5**		**3**



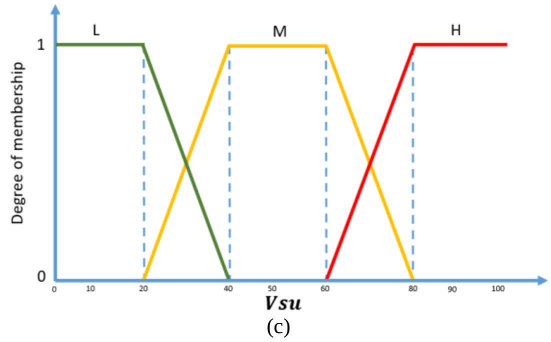


Figure 10. shows the form of fuzzy MFs before optimization, each being (a) HT, (b) Psu, and (c) Vsu.

Here is the design form of the unoptimized MF, as shown in Fig. 10, which are (a) HT, (b) Psu, and (c) Vsu.

The following is the design of the MF optimized using PSO. As a result, the optimization result of the input MF (a) HT, (b) Psu, and (c) Vsu can be seen in Fig. 11.

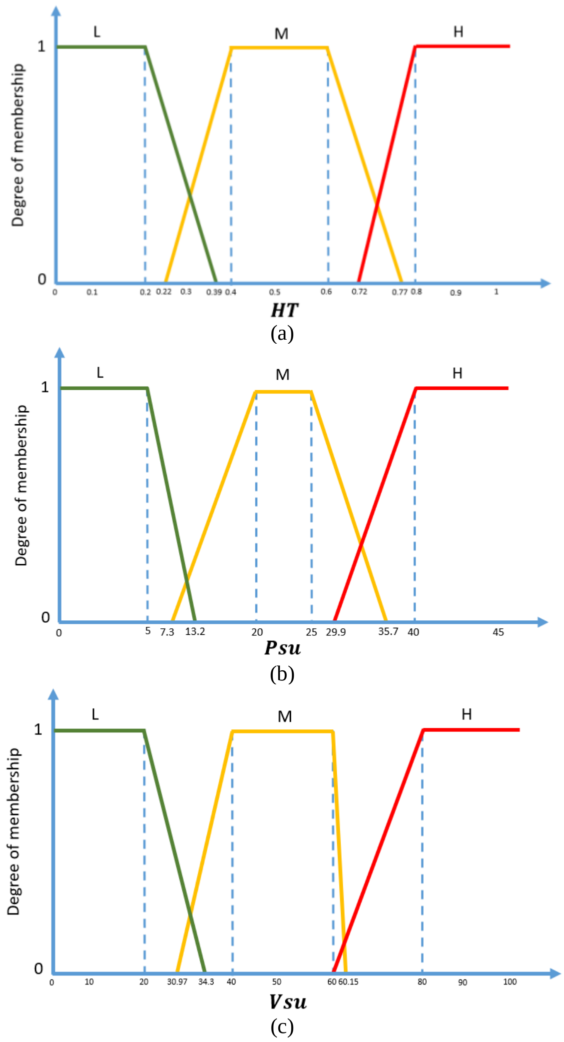


Figure 11. Shows the shape of the fuzzy MF after optimization, including (a) HT, (b) Psu, and (c) Vsu.

VI. CONCLUSIONS

In the proposed handoff scheme, the MFs of the trapezoid and shoulder for the suggested FLC model were optimized using the PSO. We considered the performance of the presented fuzzy model through two scenarios. The purpose was to determine the optimal or nearly optimal parameters for the trapezoidal and shoulder MFs to enhance defuzzification in making handoff decisions. Results indicate that through the presented scheme, the number of handoffs that occurred in CRN could be reduced with a decrease in the number of handoffs from 70%, 50%, and 30%, each performed ten times testing. So, optimizing the MF will have an impact on the handoff decision. Thus, the possibility of the ping-pong effect caused by incorrect handoff can be minimized. For future work, a more adaptive fuzzy model needs to be considered. The goal is to make the decisions related to spectrum handoff better and more optimal.

Conflict of Interest

The authors declare no conflict of interest

Author Contributions

SDR created the approach, ran exhaustive simulations, and wrote the paper. The problem formulation was clarified, validated, and the findings were evaluated by SS and IWM. The final version was accepted by all authors.

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