Optimization Of Spectrum Management in A Cognitive Radio Network using Fuzzy Logic

Y. Mimbeu [1,2], J. Matanga[1,2], Y. Malong[1,2], A. Ngalle[1,2], J.T Tasona Doko[1,2], J. F. Essiben[1,2], N. Sévérin[1,2], O. Raphaël [1,2], I. Breunon [1,2]
[1]National Higher Polytechnic School of Douala, Douala, Cameroon,
[2]Laboratory of Energy Material Modeling and Methods, University of Douala, Douala, Cameroon

Abstract **:- With the advancement of technology, especially the new generation mobile networks (5G and 6G), and the Internet of Things (IoT), the number of mobile terminals requiring access to the frequency channel in order to communicate is increasing. However, as the radio spectrum is limited in frequency, its optimal management is of paramount importance. Cognitive radio technology is a promising solution for efficient spectrum use by allowing two users, one primary and one secondary, to share the same frequency channel without disrupting communication. By combining it with artificial intelligence (AI) techniques, the results obtained could be even more convincing. This paper presents a research work on spectrum management in cognitive radio networks using fuzzy logic. Indeed, we have used fuzzy logic as a decision support system to propose a solution that will reduce interference and the number of channel switches, while maintaining a good Quality of Service (QoS). The obtained scheme performances are realized using the MatLab simulator and aim at optimizing the results of the research work of Ali et al. in [1] from which we have been inspired.**

Keywords: Mobile networks, Internet of Things, Frequency channel, Radio spectrum, Frequency, Cognitive radio, Artificial intelligence, Fuzzy logic, Interference, Channel switching, Quality of Service.

INTRODUCTION

The development of new technologies has always been dictated by the needs of the moment and the availability of the technique. We have thus moved from analog radio to digital radio, with all the progress that has followed, particularly in terms of the quality, speed and reliability of the transport of information, but also in terms of the capacity of the network. Over the years, needs have grown and new solutions and techniques have appeared. This led to the idea of software defined radio and cognitive radio is the next step. The emergence of this concept is to be directly linked with the need to manage all this new complexity relating to the environment of the radio terminal [2].

Indeed, some bands and networks are already overloaded at peak times. However, the use of the spectrum is not uniform: according to the hours of the day, according to the geographical position, a frequency band can be overloaded while another remains unused [2]. The idea therefore naturally emerged to develop tools to make better use of the spectrum. Because indeed, with the networks of future technologies, such as 5G or even 6G or even the IoT, the frequency band will be requested by several terminals, and the optimal use of the spectrum to overcome all these requests will therefore be essential. Cognitive radio is the concept that meets this challenge.

Cognitive Radio is a form of wireless communication in which a transmitter/receiver can intelligently detect which communication channels are in use and which are not, and can move into unused channels. This makes it possible to optimize the use of the available radio frequencies of the spectrum while minimizing interference with other users [2]. The principle of cognitive radio, taken up in the Institute of Electrical and Electronic Engineers (IEEE) 802.22 standard, requires alternative management of the spectrum which is as follows: a so-called secondary mobile can at any time access frequency bands that it judge free, that is to say, not occupied by the so-called primary user possessing a license on this band. The secondary user will have to give them up once the service is finished or once a primary user has shown a desire to connect [2].

The idea of cognitive radio was officially presented by Joseph Mitola in 1998. And so according to him: "A cognitive radio can know, perceive and learn from its environment and then act to simplify the life of the user" [3]. Cognitive Radio (CR) is a promising technology in terms of spectrum management, whose functionalities, essential to proper functioning, are detection, access, sharing and spectral mobility [1].

A Cognitive Radio Network (CRN) is a network without promising thread in the use of the radio spectrum in which some nodes of the network are intelligent terminals equipped with cognitive radio technology, which makes them able to access the spectrum in an opportunistic way to exploit the unused parts [5]. RC networks are classified into different categories depending on their architecture or the way they take into account interference management. They can be centralized, distributed or based on cluster technology; or have interwave, underlay or overlay interference management [4].

As we will therefore have understood, the problem lies in the optimal management of the radio spectrum. It is in this same vein that our research work focuses on the subject, by associating it as a method with fuzzy logic as a decision-making tool, in order to bring added value to existing work. Our research work is divided into 3 parts. The first part deals with the review of the literature of works on spectrum management based on fuzzy logic in cognitive radio networks; then the 2nd part deals with the material and the method that we used; and finally the third part presents the results obtained and their interpretations.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 09, September 2022

LITERATURE PAPER

In [6], the authors proposed a centralized fuzzy inference system that can allocate available bandwidth among cognitive users by considering traffic intensity, QoS type and priority. In [7], Aryal et al presented an approach to power management while reducing interference and maintaining QoS. Their algorithm takes into account the number of users, mobility, spectrum efficiency and synchronization constraint.

The authors of [8] used fuzzy logic to determine the appropriate method to detect available bandwidth. Four input parameters are considered for the selection of the spectrum detection method: (1) the probability of detection required, (2) the operational signal-to-noise ratio (SNR), (3) the time available to perform detection, and (4) a priori information.

Qin et al in [9] proposed the use of fuzzy inference rules for resource management in a distributed heterogeneous wireless environment. Fuzzy convergence is designed at two levels. First, the local convergence calculation is based on local parameters such as interference power, bandwidth of a frequency band, and path loss index. Second, local convergence calculations collected from all nodes will be aggregated to generate a global control for each node.

Naïve access to spectrum for secondary users can make the use of spectrum inefficient spectrum and increase interference with adjacent users. In [10], the author proposes an approach using the fuzzy logic system (FLS) to control spectrum access. Three descriptors are used: the spectral efficiency of use of the secondary user, his degree of mobility and his distance from the main user.

In [11], the author proposes a new strategy for logical transmission power control that allows the cognitive secondary user to achieve the required transmission rate and quality, while minimizing interference with primary users and other secondary users simultaneously.

When harmful interference is caused to a primary user, or when the quality of service perceived by a secondary user is not satisfactory, the secondary user must initiate a spectral shift to quickly free up the channel it occupies. The author's proposal in [12] is a fuzzy approach capable of making efficient spectrum transfer decisions in a context characterized by uncertain, incomplete and heterogeneous information.

An inference system based on fuzzy logic rules is proposed in [13] to estimate the possibility of the presence of the dismissed user's signal depending on the energy observed at each cognitive radio terminal.

Ali et al. [1], propose a fuzzy logic-based decision support system that jointly deals with channel selection and switching to improve the overall throughput of CRNs. The proposed scheme reduces the SU channel switching rate, while improving its quality of service and making the channel selection more adaptable.

MATERIALS AND METHODS

To help us in our simulation, we used the Matrix Laboratory software (MATLAB) which is a software used for numerical calculation purposes. Developed by The MathWorks company, MATLAB makes it possible to manipulate matrices, display curves and data, implement algorithms, create user interfaces, and can interface with other languages such as C, C++, Java, and Fortran...

Figure 3.1: MATLAB Logo

The method we have chosen for spectrum management optimization is fuzzy logic. Our proposal is based on the work of Ali et al in [1] and is part of a perspective of continuity and optimization. In this part we will first present the fuzzy logic then we will resume the work of [1] by modifying certain elements and parameters there to study a possible optimization of the results.

System modeling

The system model that we propose is composed of a primary network or Primary Network (PN) and a secondary network or Secondary Network (SN). In it, the PN consists of *n* PUs and the SN consists of *m* SUs. We use an underlay and overlay channel selection approach. The PU is a Privileged User and may use their Licensed Channel at any time without interruption. However, the SU is an opportunistic user, and can only exploit the licensed channel when the PU is not using it or when its generated interference remains below a predefined threshold. If the interference generated by the SU exceeds the specified limit, then the SU must leave the licensed channel, and thereafter must find another suitable channel for its transmissions. We consider that SUs are mobile and that the locations, accelerations and speeds of random nodes in the network may vary over time. In addition, SUs maintain a list of usable channels and update it periodically after a certain time period *t*. The SU makes a channel selection (or handoff) decision based on the Ch_{Rank} and Ch_{TR} parameters. We assume an error-free channel model and data packet loss occurs only due to PU-SU collision.

Definition of parameters

The parameters taken into account in our modeling are: the level of interference, the transmission power of the secondary user, the signal-to-noise ratio at the reception antenna of the secondary user, the transmission range of the channel, the rank of the transmission channel and the controllers [1].

Interference Temperature (IT)

Interference Temperature (IT) IT_{SU} is defined as a measure of the radio frequency (RF) power available at the receiving antenna PU. More precisely, IT_{SU} is also defined as the temperature equivalent of the RF power available at the antenna of the central receiving unit, measured in Kelvin [12]. IT_{SU} is generated by the SU transmitter and other noise sources. The IT_{SU} allows the SU and the PU to simultaneously use the licensed channel. However, the SU must ensure that its generated interference is below an IT_{SU} threshold; otherwise, the SU must immediately release the licensed channel [1].

The Transmission Power (TP)

Transmission Power (TP) TP_{SU} is the value of the available power at which the SU can transmit its data to the receiving antenna of the PU [13]. Controlling this parameter allows the SU to use the licensed channel simultaneously while maintaining a certain level of QoS for its transmissions. In the event that no PU is operating on the licensed channel, the SU may transmit with maximum power to improve reception probability and improve QoS for its transmissions [1].

The initial TP_{SU} value is used for initial communication between communicating peer nodes, and later this value can be adjusted to avoid harmful interference with the PU and other SUs operating on that particular licensed channel.

Signal to noise ratio

Ensuring the transmission power SU below a given threshold while maintaining a certain level of QoS at the receiving antenna SU is a critical and difficult task. However, the Signal Noise Ratio (SINR) measured at the SU receiving antenna can be used to determine the QoS of SU transmissions. Additionally, it can be used to determine the minimum value of transmit power required by the SU to minimize potential interference with the PU. Thus, controlling the SINR parameter allows the SU to simultaneously use the licensed channel while maintaining a certain level of QoS for its own transmissions as well [1].

Signal transmission range

The channels available to SUs are remarkably heterogeneous in terms of channel error rate and Transmission Range (TR). We also know that channels with lower transmission ranges are located in higher frequency bands. Therefore, Channel Transmission Range Ch_{TR} has a significant impact on channel switching under SU mobility. Therefore, Ch_{TR}-based channel selection can significantly reduce the channel switching rate by providing sufficient transmission range to cover the pair of communicating SU nodes [1].

The rank of the transmission channel

Provides availability of channels sensitive to PU activity. Channels indexed under Channel Rank Ch_{Rank} are more stable and provide less collisions as well as less interference with PUs. Thus, channel selection based on Ch_{Rank} provides the minimum channel switching rates as well as the ability to make known switching decisions [1].

Definition of logic controllers

Here we define two logic controllers. One to manage the cohabitation between PU and Su to minimize interference and guarantee an acceptable Qos. And the other which allows you to select the best channel available if handover is necessary.

Logic controller 1

The first fuzzy logic controller (CL1) is designed to make a qualitative estimate of the power at which the SU transmits its data without interfering with other transmissions of the PU and SUs while maintaining a certain QoS for its own transmissions. The purpose of CL1 is to minimize the channel switching rate while adjusting TPSU in overlapped transmissions, which only happens when the transmission of the SU is in progress and the PU has also arrived, and thus, the SU must either continue to use the channel depending on the sublayer approaching or immediately switch to another appropriate channel upon making the decision to hand over. The CL1 takes the fuzzy inference rules shown in the next section as input and makes the appropriate decision to handle TPSU, or transfer the communication to another channel. In the case of a transfer, the operation of CL2 takes place [1].

Logic Controller 2

The CL2 is designed to select the best channel from the list of available channels, which allows the SU to use a channel for a long time and possibly minimizes the channel switching rate. When the SU must select a new channel, it considers Ch_{Rank} and Ch_{TR} as input parameters. After that, it puts them into the fuzzifier to get the membership functions or antecedents. The inference engine applies the fuzzy rules and passes the antecedent to the defuzzifier to get the precise consequent on which the SU will make the most appropriate decision [1].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 09, September 2022

3.1. Spectrum management optimization using fuzzy logic

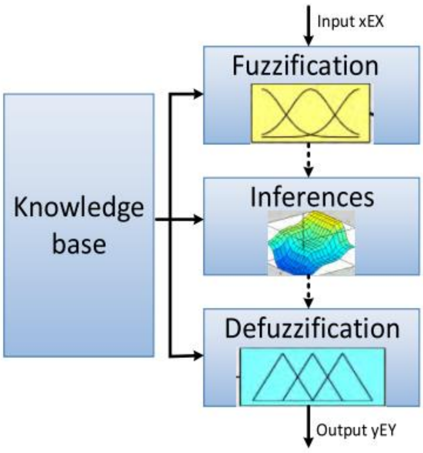


Figure 3.2: Fuzzy system architecture [1]

The inference method that we will use is that of Mamdani which comes in a few steps that we will cover, namely: the fuzzification of input variables, the definition of sets and fuzzy rules, the aggregation of output rules and the defuzzification.

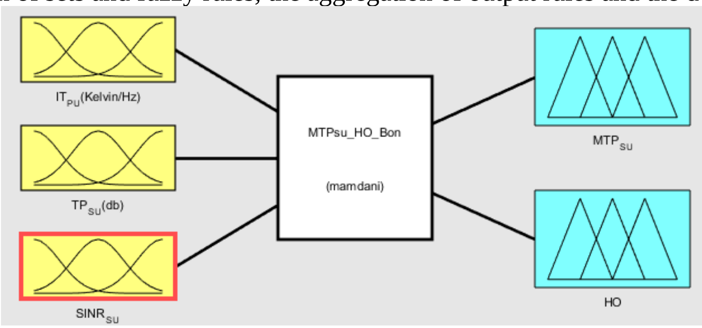


Figure 3.2: Mamdani inference engine

Fuzzification of input variables

Here we will determine the input variables, of which we will give linguistic variables and values, then we will give their universe of discourse. Our input variables are the previously dened parameters, namely:

- ITSU interference level which can be low, medium or high
- The transmission power TPSU which can be low, medium or high
- The SINRSU signal to noise ratio which can be low, medium or high
- The transmission range of the ChTR signal which can be weak, medium or strong
- The threshold level of the transmit ChRank signal which can be weak, medium or strong.

Definition of fuzzy sets

To define fuzzy sets it would be interesting to delimit the universe of discourse:

- ITSU interference temperature between 0 and 400 kelvin/Hz
- The transmission power TPSU between 0 and 20 db
- The SINRSU signal-to-noise ratio between 0 and 25
- The transmission range of the ChTR signal included 0 and 5000 m
- The threshold level of the ChRank signal included between 0 and 100.

Table 3.1: Fuzzification of input variables

Inputs	Linguistic variables	Linguistic values	Universe of speech
IT_{SU}	Interference Temperaure	Low, Medium, High	[0 ; 400] Kelvin/Hz
TP_{SU}	Transmission Power	Low, Medium, High	[0 ; 20] db
$SINR_{SU}$	Signal to noise ratio	Low, Medium, High	[0 ; 25]
Ch_{TR}	Channel Transmission Range	Low, Medium, High	[0 ; 5000] m
Ch_{Rank}	Channel Transmission Rank	Low, Medium, High	[0 ; 100]

Definition of fuzzy rules

Before defining the fuzzy rules, it is important to introduce new variables that materialize the decisions to be made at the output of each rule.

- **HandOver (HO**) or channel change: this variable translates the secondary user's decision to release the busy channel and search for the best available channel in order to continue the communication in progress;

- **Manage Transmission Power of second user (MTPsu)** which translates the fact that the conditions make it possible to continue the communication in the current channel but to manage the transmission power of SU to reduce the level of interference, this with a view to not harming the main user, while maintaining good quality on duty ;
- **Research wait (Rwait):** in the event that the HO procedure is initiated, the SU will have to look for another available channel that optimizes its expectations, in order to continue the communication. It scans the available channels until it finds the right one;
- **Select channel (SELch):** if the HO procedure is initiated, the SU must select, after analyzing the available channels, the best available channel to continue the communication.

HO and MTPsu intervene as output decision following the conditions enacted in each rule taking into account the interference temperature of the primary user (ITpu) and the transmission power of the secondary user (TPsu):

1. Si (IT_P_U(Kelvin/Hz) est Faible) et (TP_S_U(db) est Faible) et (SINR_S_U est Faible) alors (MTP_S_U est Oui)(HO est Non) (1)
2. Si (IT_P_U(Kelvin/Hz) est Faible) et (TP_S_U(db) est Faible) et (SINR_S_U est Moyen) alors (MTP_S_U est Oui)(HO est Non) (1)
3. Si (IT_P_U(Kelvin/Hz) est Faible) et (TP_S_U(db) est Faible) et (SINR_S_U est Fort) alors (MTP_S_U est Oui)(HO est Non) (1)
4. Si (IT_P_U(Kelvin/Hz) est Moyen) et (TP_S_U(db) est Faible) et (SINR_S_U est Faible) alors (MTP_S_U est Oui)(HO est Non) (1)
5. Si (IT_P_U(Kelvin/Hz) est Moyen) et (TP_S_U(db) est Faible) et (SINR_S_U est Moyen) alors (MTP_S_U est Oui)(HO est Non) (1)
6. Si (IT_P_U(Kelvin/Hz) est Moyen) et (TP_S_U(db) est Faible) et (SINR_S_U est Fort) alors (MTP_S_U est Oui)(HO est Non) (1)
7. Si (IT_P_U(Kelvin/Hz) est Fort) et (TP_S_U(db) est Faible) et (SINR_S_U est Faible) alors (MTP_S_U est Non)(HO est Oui) (1)
8. Si (IT_P_U(Kelvin/Hz) est Fort) et (TP_S_U(db) est Faible) et (SINR_S_U est Moyen) alors (MTP_S_U est Oui)(HO est Non) (1)
9. Si (IT_P_U(Kelvin/Hz) est Fort) et (TP_S_U(db) est Faible) et (SINR_S_U est Fort) alors (MTP_S_U est Oui)(HO est Non) (1)
10. Si (IT_P_U(Kelvin/Hz) est Faible) et (TP_S_U(db) est Moyen) et (SINR_S_U est Faible) alors (MTP_S_U est Oui)(HO est Non) (1)
11. Si (IT_P_U(Kelvin/Hz) est Faible) et (TP_S_U(db) est Moyen) et (SINR_S_U est Moyen) alors (MTP_S_U est Oui)(HO est Non) (1)
12. Si (IT_P_U(Kelvin/Hz) est Faible) et (TP_S_U(db) est Moyen) et (SINR_S_U est Fort) alors (MTP_S_U est Non)(HO est Oui) (1)
13. Si (IT_P_U(Kelvin/Hz) est Moyen) et (TP_S_U(db) est Moyen) et (SINR_S_U est Faible) alors (MTP_S_U est Oui)(HO est Non) (1)
14. Si (IT_P_U(Kelvin/Hz) est Moyen) et (TP_S_U(db) est Moyen) et (SINR_S_U est Moyen) alors (MTP_S_U est Oui)(HO est Non) (1)
15. Si (IT_P_U(Kelvin/Hz) est Moyen) et (TP_S_U(db) est Moyen) et (SINR_S_U est Fort) alors (MTP_S_U est Non)(HO est Oui) (1)
16. Si (IT_P_U(Kelvin/Hz) est Fort) et (TP_S_U(db) est Moyen) et (SINR_S_U est Faible) alors (MTP_S_U est Non)(HO est Oui) (1)
17. Si (IT_P_U(Kelvin/Hz) est Fort) et (TP_S_U(db) est Moyen) et (SINR_S_U est Moyen) alors (MTP_S_U est Oui)(HO est Non) (1)
18. Si (IT_P_U(Kelvin/Hz) est Fort) et (TP_S_U(db) est Moyen) et (SINR_S_U est Fort) alors (MTP_S_U est Oui)(HO est Non) (1)
19. Si (IT_P_U(Kelvin/Hz) est Faible) et (TP_S_U(db) est Fort) et (SINR_S_U est Faible) alors (MTP_S_U est Non)(HO est Oui) (1)
20. Si (IT_P_U(Kelvin/Hz) est Faible) et (TP_S_U(db) est Fort) et (SINR_S_U est Moyen) alors (MTP_S_U est Oui)(HO est Non) (1)
21. Si (IT_P_U(Kelvin/Hz) est Faible) et (TP_S_U(db) est Fort) et (SINR_S_U est Fort) alors (MTP_S_U est Oui)(HO est Non) (1)
22. Si (IT_P_U(Kelvin/Hz) est Moyen) et (TP_S_U(db) est Fort) et (SINR_S_U est Faible) alors (MTP_S_U est Non)(HO est Oui) (1)
23. Si (IT_P_U(Kelvin/Hz) est Moyen) et (TP_S_U(db) est Fort) et (SINR_S_U est Moyen) alors (MTP_S_U est Non)(HO est Oui) (1)
24. Si (IT_P_U(Kelvin/Hz) est Moyen) et (TP_S_U(db) est Fort) et (SINR_S_U est Fort) alors (MTP_S_U est Oui)(HO est Non) (1)
25. Si (IT_P_U(Kelvin/Hz) est Fort) et (TP_S_U(db) est Fort) et (SINR_S_U est Faible) alors (MTP_S_U est Non)(HO est Oui) (1)
26. Si (IT_P_U(Kelvin/Hz) est Fort) et (TP_S_U(db) est Fort) et (SINR_S_U est Moyen) alors (MTP_S_U est Non)(HO est Oui) (1)
27. Si (IT_P_U(Kelvin/Hz) est Fort) et (TP_S_U(db) est Fort) et (SINR_S_U est Fort) alors (MTP_S_U est Non)(HO est Oui) (1)

Figure 3.3: Fuzzy rules for managing the transmission power of the SU taking into account IT_{PU} and $SNIR_{SU}$

In the event that the handover decision has been made, the SU will be called upon to seek and choose another available channel to continue its communication. SEL_{ch} and R_{wait} intervene as exit decision following the conditions enacted in each rule taking into account Ch_{Rank} and Ch_{TR}. That is, the SU waits and continues to search for a favorable channel until it finds and selects it:

1. Si (Ch_R_a_n_k est Faible) et (Ch_T_R(m) est Faible) alors (SEL_c_h est Non)(R_w_a_i_t est Oui) (1)
2. Si (Ch_R_a_n_k est Faible) et (Ch_T_R(m) est Moyen) alors (SEL_c_h est Oui)(R_w_a_i_t est Non) (1)
3. Si (Ch_R_a_n_k est Faible) et (Ch_T_R(m) est Fort) alors (SEL_c_h est Oui)(R_w_a_i_t est Non) (1)
4. Si (Ch_R_a_n_k est Moyen) et (Ch_T_R(m) est Faible) alors (SEL_c_h est Oui)(R_w_a_i_t est Non) (1)
5. Si (Ch_R_a_n_k est Moyen) et (Ch_T_R(m) est Moyen) alors (SEL_c_h est Oui)(R_w_a_i_t est Non) (1)
6. Si (Ch_R_a_n_k est Moyen) et (Ch_T_R(m) est Fort) alors (SEL_c_h est Oui)(R_w_a_i_t est Non) (1)
7. Si (Ch_R_a_n_k est Fort) et (Ch_T_R(m) est Faible) alors (SEL_c_h est Non)(R_w_a_i_t est Oui) (1)
8. Si (Ch_R_a_n_k est Fort) et (Ch_T_R(m) est Moyen) alors (SEL_c_h est Oui)(R_w_a_i_t est Non) (1)
9. Si (Ch_R_a_n_k est Fort) et (Ch_T_R(m) est Fort) alors (SEL_c_h est Oui)(R_w_a_i_t est Non) (1)

Figure 3.4: Fuzzy channel selection rule considering ChRank and ChTR

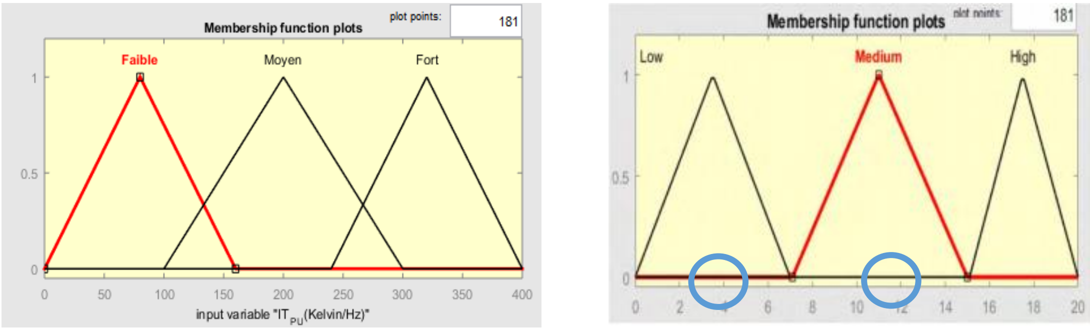
RESULTS AND INTERPRETATIONS

After modeling our system, describing the methodology and denying our parameters in the previous chapter, we will now implement our solution. This third and last chapter is therefore devoted to the simulation of our model and the presentation of the results. By doing a comparative study on recent work we will also evaluate our optimization.

Comparative studies

In comparison with the work of Ali et al., we had to modify the values of the parameters. In this case the range of values of fuzzy sets and also some inference rules. In fact, we have denied ranges of values and rules that seem closer to reality while always having in mind the minimization of interference from the primary user, the improvement of the quality of service of the secondary user and reducing the number of handovers. To illustrate our remarks we will study a set or work of Ali et al., and compare it to a set or of the same parameter that we have denied. In the overall model or (figure b) type chosen in the article by Ali and AL. we can see that the interference values do not overlap and each have distinct ranges.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 09, September 2022



(a) Ensemble or TPSU (b) Ensemble or typical TPSU from the Ali et al.

Figure 3.5: Comparison set or used and set or type of the article from Ali et al.

However we found that this way of choosing the ranges of values does not optimally reflect the reality because it could arise an ambiguity of the correspondence of a value at the time of the defuzzication. If, for example, according to the diagram above, the value of TPsu is 7, its membership degree would be neither Low nor Middle, and would be 0, which corresponds to our failure that our model wanted to correct. Regarding the fuzzy rules, we modified some rules from the work of Ali et al. which seemed somewhat incoherent to us. In this case rules 21 and 24 of logic controller 1 and rule 1 of logic controller 2.

20	Hgh	Lw	Med	✓	
21	Hgh	Lw	Hgh		✓
22, 23, 24	Hgh	Med	Lw, Med, Hgh		✓
25, 26, 27	Hgh	Hgh	Lw, Med, Hgh		✓

(a) Modification des règles floues 21 et 24 du CL1 de Ali et al.

Rule no.	Ch_{Rank}	Ch_{TR}	SEL_{ch}	R_{wait}
1	Lw	Lw		✓
2	Lw	Med		✓
3	Lw	Hgh	✓	
4	Med	Lw	✓	

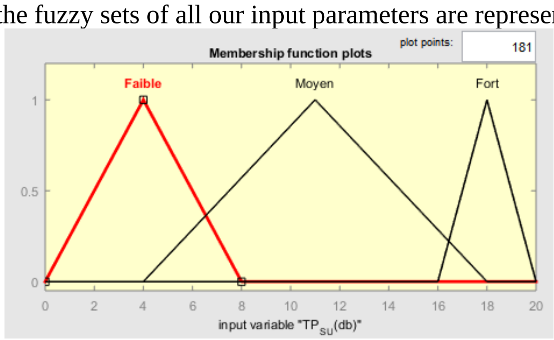
(b) Modification of CL2 fuzzy rule 1 of Ali et al.

Figure 3.6: Comparing and modifying fuzzy rules

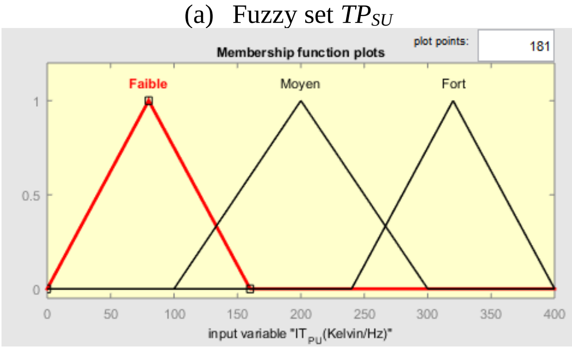
Optimization

Definition of fuzzy sets

As described in the previous chapter, the fuzzy sets of all our input parameters are represented in the following diagrams:

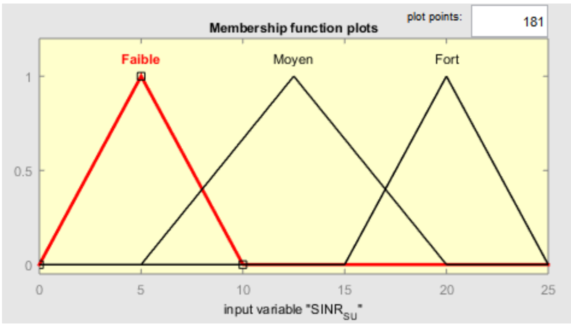


(a) Fuzzy set TP_{SU}



(b) Fuzzy set IT_{PU}

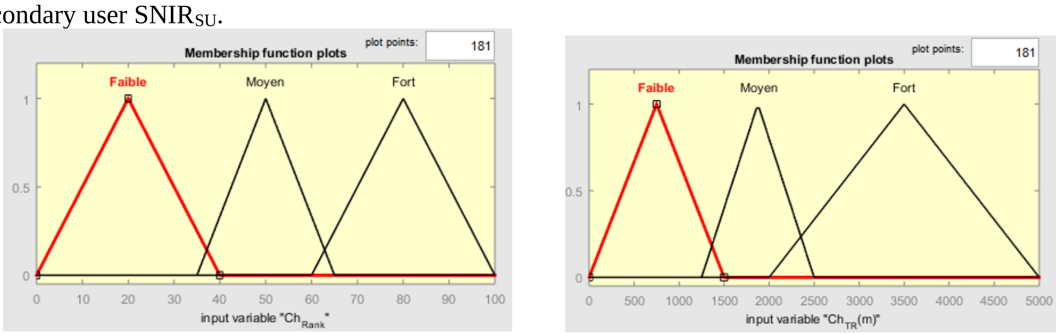
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 09, September 2022



(c) Fuzzy set $SNIR_{SU}$

Figure 4.2: Fuzzy sets of logic controller 1

In the fuzzy sets considered in our inference engine 1, figure (a) represents the set or transmission power of the secondary user TP_{SU}; Figure (b) depicts the IT_{SU} primary user interference set or temperature; and figure (c) represents the entire signal-to-noise ratio of the secondary user $SNIR_{SU}$.



(a) Fuzzy set Ch_{Rank} (b) Fuzzy set Ch_{TR}

Figure 4.3 : Fuzzy sets of logic controller 2

In the fuzzy sets taken into account in our inference engine 2, figure (a) represents the set or of the threshold channel ChRank; and Figure (b) shows the whole or transmission range of the channel.

Definition of fuzzy rules

The rules of fuzzy CL1 denials in Matlab are represented by the following diagram:

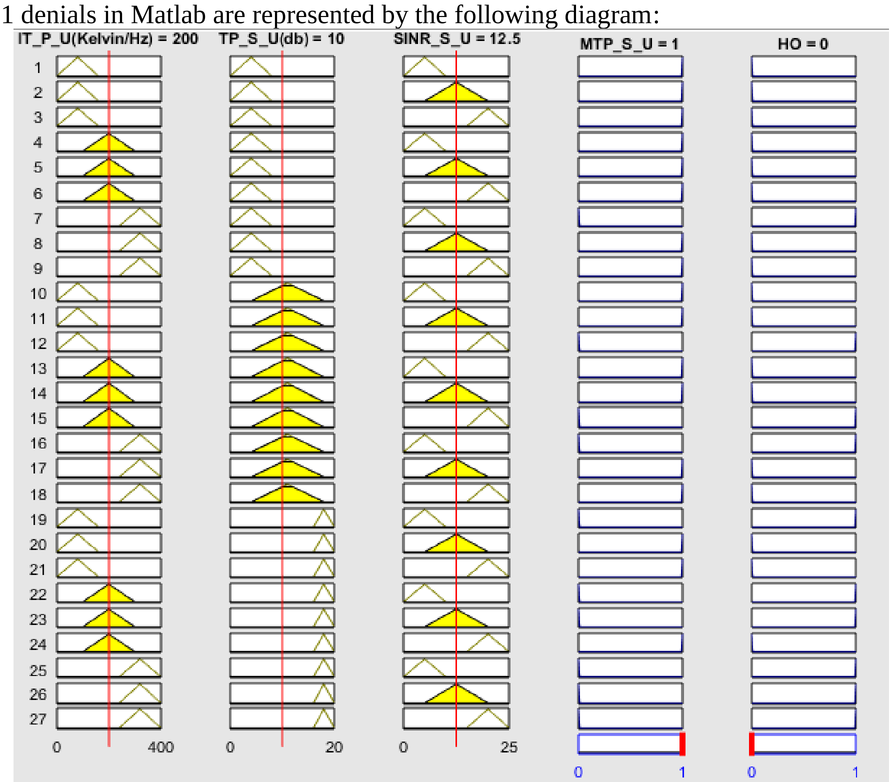


Figure 4.4: Diagrams of fuzzy rules in Matlab

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 09, September 2022

This diagram represents the set of 27 fuzzy rules entered into the simulator of Matlab, with as input variables the interference temperature of the primary user IT_{PU}, the transmission power of the secondary user TP_{SU}, and the signal-to-noise ratio of the secondary user $SNIR_{SU}$. And for output variables MTP_{SU} which represents the US power management decision, and the HO which represents the handover or channel change decision. The rules of fuzzy CL2 denials in Matlab are represented by the following diagram:

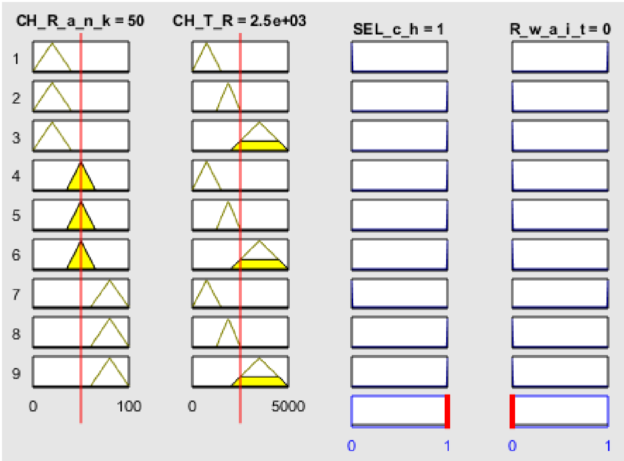


Figure 4.5: Diagram of fuzzy rules in Matlab

This diagram represents the set of 9 fuzzy rules entered in the simulator of Matlab, with as input variables the transmission range of the channel ChTR and the transmission threshold channel ChRank. And for output variables SELch which represents the decision to select the channel, and Rwait which represents the decision to wait and look for the right channel to hang on to.

Results

In this part we present the results we obtained and the optimization brought to the work of Ali et al. The results of our work are shown in the diagrams below.

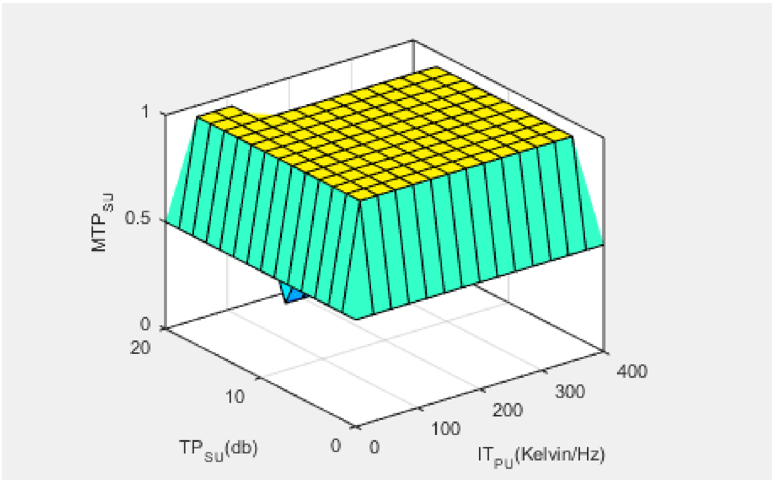


Figure 4.6: SU Power management considering TP_{SU} and IT_{PU}

The diagram above is the 3-dimensional surface representation of the secondary user transmission power management MTP_{SU} taking into account the transmission power of the secondary user TP_{SU} in decibel (db) and the interference temperature of the primary user IT_{PU} in Kelvin/Hz. We can see that except for high values of IT_{PU} and TP_{SU} it is advisable to manage, i.e. to reduce the transmission power of the secondary user.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 09, September 2022

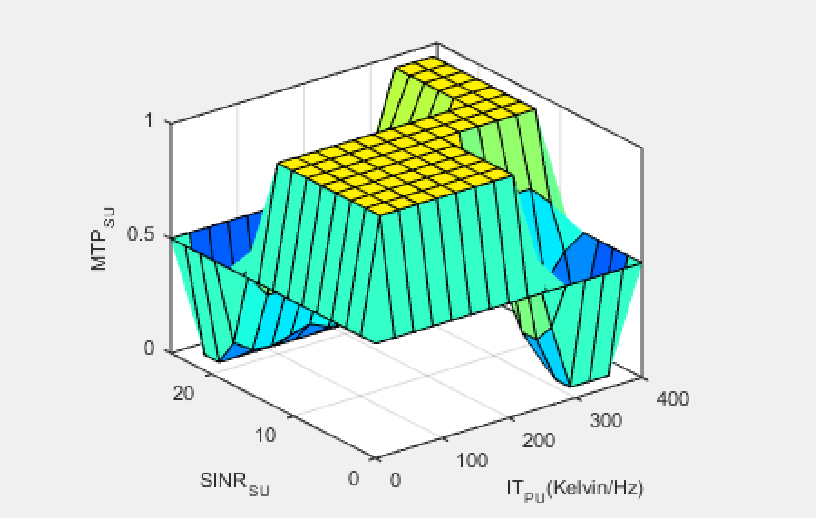


Figure 4.7: SU power management considering $SINR_{SU}$ and IT_{PU}

The diagram above is the 3-dimensional areal representation representing the secondary user's transmit power management decision considering the secondary user's signal-to-noise ratio $SNIR_{SU}$ and the user's interference temperature primary IT_{PU} in Kelvin/Hz. The management solution is preferred when interference signal quality is low. We notice an improvement in the quality of service materialized by the enhancement of the management of the power of the SU.

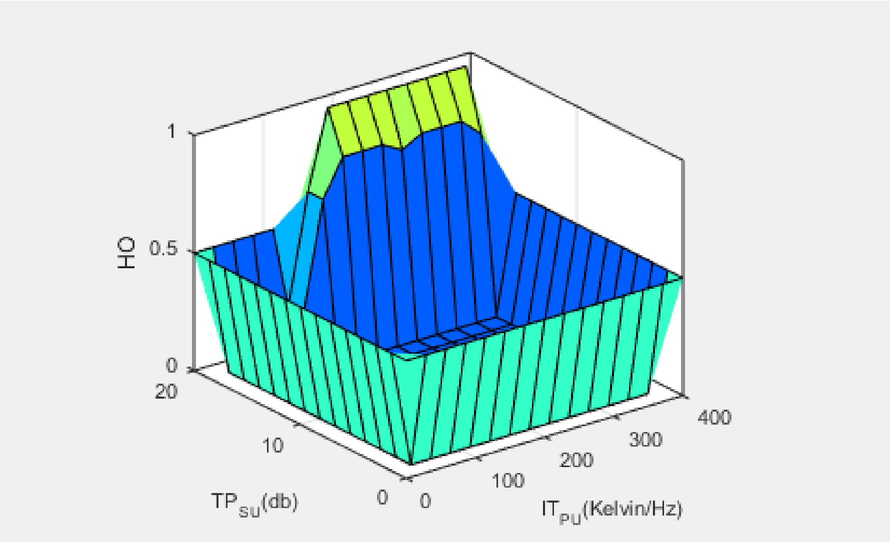


Figure 4.8: Handover decision considering TPSU and ITPU

The diagram above is the 3-dimensional surface representation of the secondary user's Handover HO decision taking into account the secondary user's transmit power TP_{SU} and the primary user's interference temperature IT_{PU}. We can see for high values of IT_{PU} and TP_{SU} it is advisable to proceed with the Handover so as not to reduce the quality of the communication of the PU. However, in comparison with previous works, the top of the graph is refined, thus materializing the reduction in the number of handovers.

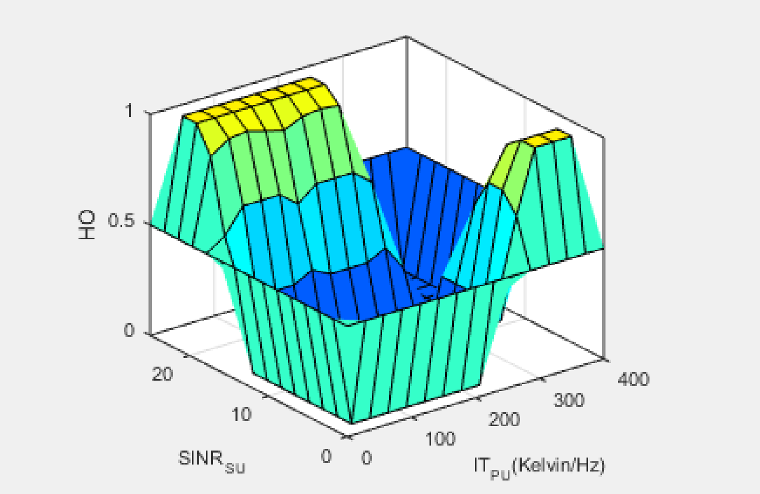


Figure 4.9: Handover decision considering $SINR_{SU}$ and IT_{PU}

The diagram above is the 3-dimensional surface representation of the secondary user's handover decision taking into account the signal to noise ratio of the secondary user $SINR_{SU}$ and the interference temperature of the primary user IT_{PU} in Kelvin/ Hz. The management solution is preferred when interference signal quality is low.

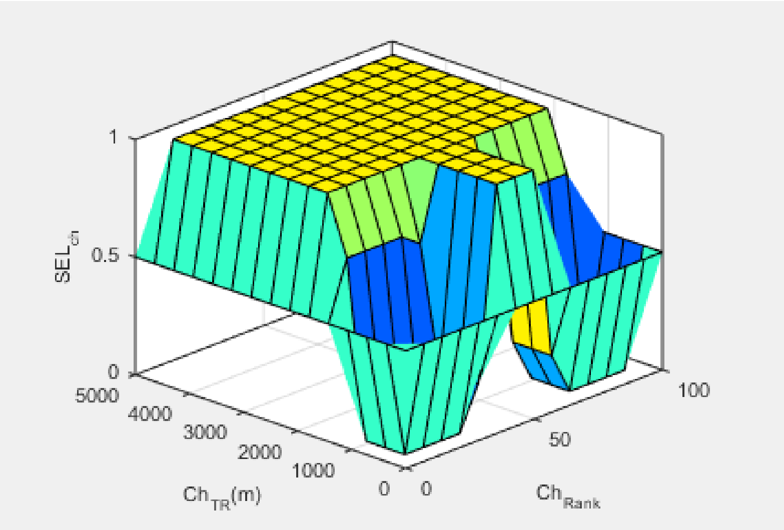


Figure 4.10: Channel selection decision considering Ch_{Rank} and Ch_{TR}

The above diagram is the 3-dimensional surface representation of the Ch_{Rank} transmission channel rank selection decision and the Ch_{TR} channel transmission range in meters (m). The channel selection decision is made in most cases where the transmission range is high. Thus the waiting time before selecting the channel is reduced and the fluidity and good quality of the communication can be maintained.

CONCLUSION

In short, after analyzing recent research works, we have made an optimization to those of Ali et al., which were according to our research the most relevant, by modifying the parameters of his fuzzy sets and some of his fuzzy rules . By using the Matlab simulator, we were able to demonstrate and present our results. However, although the results of our work are fairly successful, we believe that it is possible to go further in optimization by associating, for example, with fuzzy logic another method, the bee colony algorithm.

REFERENCES

[1] Amjad Ali, Laraib Abbas, Muhammad Shaq, Ali Kashif Bashir, Muhammad Khalil Afzal, Hannan Bin Liaqat, Muhammad Hameed Siddiqi, and Kyung Sup Kwak. Hybrid fuzzy logic scheme for efficient channel utilization in cognitive radio networks. IEEE Access, 7 :24463-24476, 2019.
[2] Badr Benmammar and Asma Amraoui. Réseaux de radio cognitive : Allocation des ressources radio et accès dynamique au spectre. arXiv preprint arXiv :1407-2705, 2014.
[3] Joseph Mitola and Gerald Q Maguire. Cognitive radio : making software radios more personal. IEEE personal communications, 6(4) :13-18, 1999.
[4] Ian F Akyildiz, Won-Yeol Lee, Mehmet C Vuran, and Shantidev Mohanty. A survey on spectrum management in cognitive radio networks. IEEE Communications magazine, 46(4) :40-48, 2008.
[5] Emna TRIGUI. Gestion multi-agents du spectre pour des terminaux mobiles à radio cognitive. PhD thesis, UTT - Université de Technologie de Troyes, 2013.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 09, September 2022

[6] Prabhjot Kaur, Moin Uddin, and Arun Khosla. Fuzzy based adaptive bandwidth allocation scheme in cognitive radio networks. In 2010 Eighth International Conference on ICT and Knowledge Engineering, pages 41-45. IEEE, 2010.

[7] Sapan Raj Aryal, Hariom Dhungana, and Kundan Paudyal. Novel approach for interference management in cognitive radio. In 2012 Third Asian Himalayas International Conference on Internet, pages 1-5. IEEE, 2012.

[8] Marja Matinmikko, Javier Del Ser, Tapio Rauma, and Miia Mustonen. Fuzzy-logic based framework for spectrum availability assessment in cognitive radio systems. IEEE Journal on selected areas in communications, 31(11) : 21732184, 2013.

[9] Hang Qin, Li Zhu, and Desheng Li. Artificial mapping for dynamic resource management of cognitive radio networks. In 2012 8th International Conference on Wireless Communications, Networking and Mobile Computing, pages 1-4. IEEE, 2012.

[10] Hong-Sam T Le, Hung D Ly, and Qilian Liang. Opportunistic spectrum access using fuzzy logic for cognitive radio networks. International Journal of Wireless Information Networks, 18(3) :171-178, 2011.

[11] Zeljko Tabakovic, Sonja Grgic, and Mislav Grgic. Fuzzy logic power control in cognitive radio. In 2009 16th International Conference on Systems, Signals and Image Processing, pages 15. IEEE, 2009.

[12] T Charles Clancy. Formalizing the interference temperature model. Wireless Communications and Mobile Computing, 7(9) :1077-1086, 2007.

[13] Min Xie, Wei Zhang, and Kai-Kit Wong. A geometric approach to improve spectrum efficiency for cognitive relay networks. IEEE Transactions on Wireless Communications, 9(1) :268281, 2010.

[14] Cours d'asservissements linéaires, chaptitre La logique floue. non publiée, 2017.