

Chapter 4

Spectrum Handover based on Fuzzy Logic in Cognitive Radio Networks

4.1 Introduction to Spectrum Handover

As mentioned earlier in this thesis, a secondary user (SU) in a cognitive radio network (CRN) adopts one of three paradigms, underlay, overlay and interweave [9]. In this chapter, the underlay paradigm is considered, where a SU is allowed to communicate provided no significant interference is caused to primary, also called licensed, users (PUs) [3]. SUs are characterized by cognitive radio capabilities, that is, in order to access certain frequencies, a SU has to continually monitor the radio spectrum to identify spectrum opportunities, to reliably detect the presence of PUs, and to evaluate the interference that the secondary node may cause on primary transmission. This process is referred to as *Spectrum Sensing*. As a result of spectrum sensing, if a PU is detected and if the SU is causing harmful interference to it or the Quality of Service (QoS) of the SU is not satisfying, the frequency channel has to be quickly vacated and the SU needs to switch to another channel initiating the process of the so called spectrum handover.

In this chapter, we focus on how a SU makes the handover decision based on the information available from the spectrum sensing. Actually, the decision of switching to a different frequency channel can be challenging due to the uncertainty in any wireless channel. Additionally, multiple decision making inputs (e.g. power levels, signal to noise ratios (SNR), Quality of Service (QoS) indicators, etc.) are heterogeneous and not directly comparable. Finally, the spectrum handover algorithm implemented at the SU terminal side has to be characterized by low complexity and reduced execution time to quickly vacate licensed channels when required. To mitigate the effect of these challenging problems, we propose a fuzzy logic based handover technique to deal with the incompleteness, uncertainty and heterogeneity of

a cognitive radio scenario.

Fuzzy logic is a mathematical tool particularly appropriate to model problems in which the available inputs are qualitatively interpreted. When the information available about the system inputs is mostly heterogeneous, fuzzy modeling is able to transform heterogeneous and qualitative information into homogeneous membership values, which can then be processed through a set of fuzzy inference rules. The technique proposed in this chapter is simple enough to guarantee low complexity implementation and quick spectrum mobility as required in cognitive radio networks, to avoid any possible harm to the PU's transmission.

4.2 Model of The Proposed Handover Approach

Consider a Cognitive Radio Network (CRN) consisting of a group of secondary nodes operating in TV frequency bands. The primary signal of interest here is digital (DVB-T) TV. Secondary Users (SUs) in the CRN are ruled by the 802.22 IEEE standard [22]. An Additive White Gaussian Noisy (AWGN) channel is assumed. It is required to determine whether it is required to vacate the previously accessed channel or not.

The fuzzy-based spectrum handover proposed in this chapter is implemented at the SU. It consists of three sequential phases. The first phase is an FIS with the purpose of estimating the distance between the PU and SU. The second phase is applying a simplified path loss model to estimate the interference caused by the SU on the PU terminal. The final phase is another FIS that aims to find the decision of whether handover is necessary or not. A detailed description of each phase follows in next subsections.

4.2.1 Proposed Approach

If a PU is detected, the handover decision taking algorithm must take place to decide whether vacating the channel is necessary to avoid harming the primary transmission or not. The flow

of the presented approach is shown in the flowchart of Fig. 4.1.

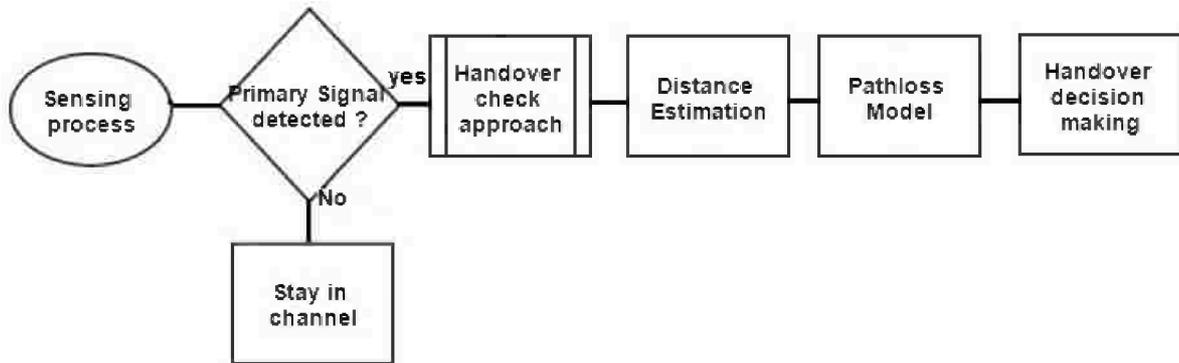


FIGURE 4.1: Flowchart of The Presented Approach

4.2.2 Distance Estimating phase

This step is required for estimating the distance between the PU and the SU. Estimating the distance depends on two main variables, signal strength received at the SU from the PU (Rx_{PU}) and the estimated PU's signal-to-noise-ratio (SNR_{PU}). Note that, if the signal strength at the SU receiver is *low*, it does not mean that the distance between the PU and the SU is *high*, since the SU has not the information about the power at which the PU is transmitting (P_{PU}). That's why an estimate of SNR_{PU} is required as well especially that the channel assumed here is an AWGN channel, thus, SNR_{PU} can be an indication of the transmitted primary signal. It is assumed that the SU is able to qualitatively determine an estimation of SNR_{PU} [23].

The distance estimating phase consists of, as seen in Fig. 4.2, an FIS that takes two inputs (Rx_{PU} and SNR_{PU}) and results in one output which is an estimate of the distance between PU and SU. Each linguistic variable is characterized by three sets (*Low*, *Medium* and *High*). A Gaussian membership function is used for each set as shown in Fig. 4.3, 4.4 and 4.5.

Using a group of IF-THEN rules that covers all possible relations between Rx_{PU} and SNR_{PU} linguistic values, a distance estimate can be obtained. This group of IF-THEN



FIGURE 4.2: Distance Estimating FIS

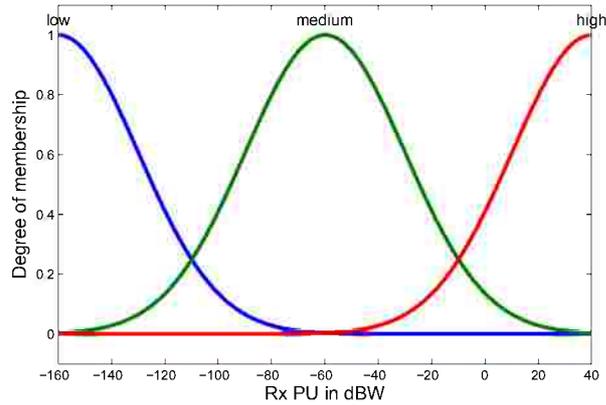


FIGURE 4.3: Membership Functions of Rx_{PU}

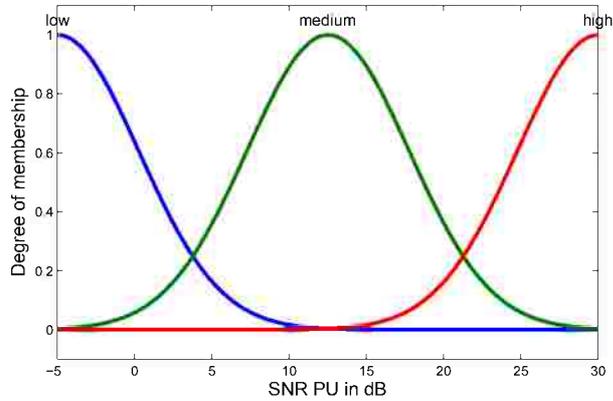


FIGURE 4.4: Membership Functions of SNR_{PU}

rules is presented in Table 4.1. These rules are defined to realize the comparison between the signal strength received by the SU from the PU, Rx_{PU} , and the estimated SNR_{PU} . For example, in rule 3, if the Rx_{PU} is *low*, but the estimated SNR_{PU} is *high*, then the distance between PU and SU is estimated to be *high*.

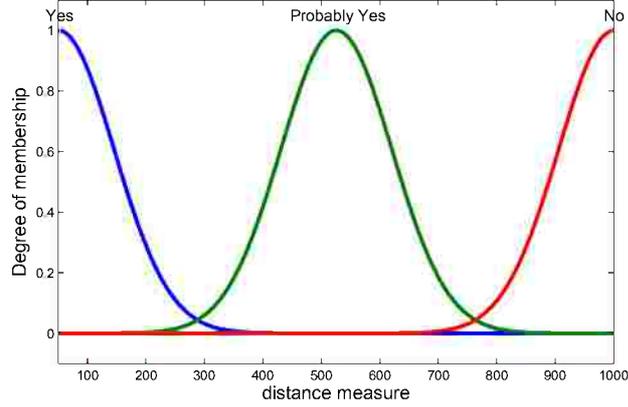


FIGURE 4.5: Membership Functions of the Distance Estimate

No.	Rx_{PU}	SNR_{PU}	Distance
1	low	low	medium
2	low	medium	medium
3	low	high	high
4	medium	low	low
5	medium	medium	low
6	medium	high	medium
7	high	low	low
8	high	medium	low
9	high	high	low

TABLE 4.1: IF-THEN RULES of the Distance Estimating FIS

Fig. 4.6 shows the fuzzy reasoning process.

4.2.3 Interference Estimating Phase

For the SU to accurately decide whether it is necessary to perform handover or not, it is required to estimate the interference it causes on the PU's transmission which has the higher transmission priority. The SU is aware, now, of the distance to the PU. Therefore, as shown in Fig. 4.7, using this distance estimate with the transmitted power of the SU (P_{SU}) and applying a path loss model will give a very good estimate of the power received at the PU terminal.

The path loss model considered in this thesis is the "Simplified Path Loss Model" which captures main characteristics of ray tracing and is considered good for high-level analysis

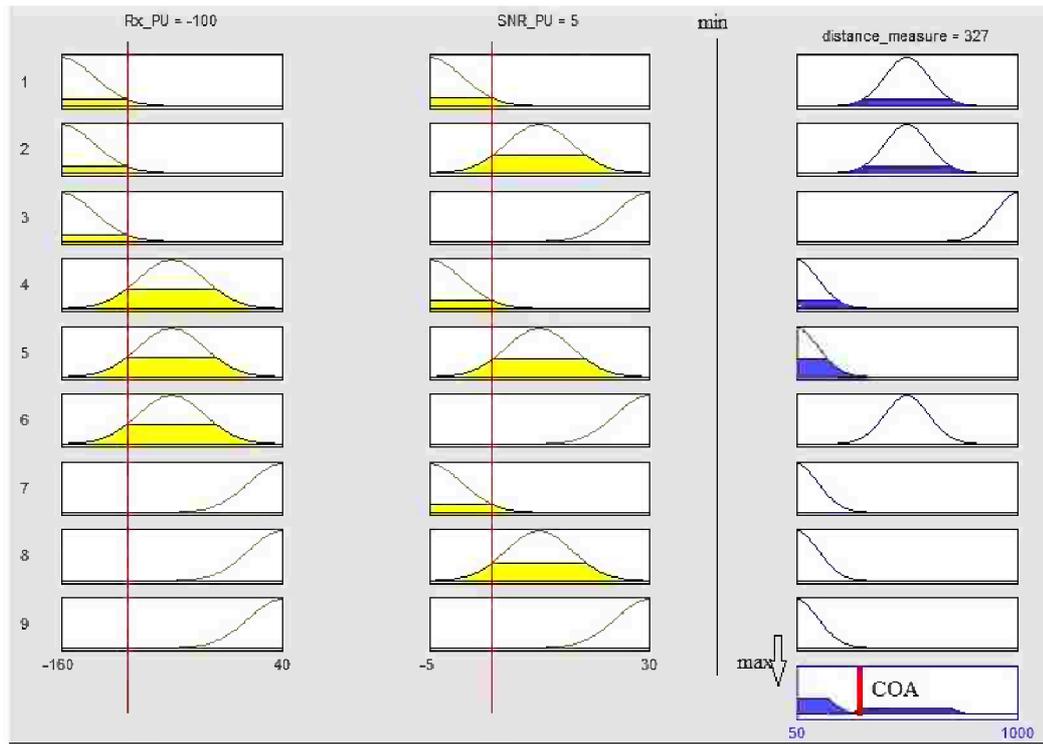


FIGURE 4.6: Fuzzy reasoning of the distance estimation phase

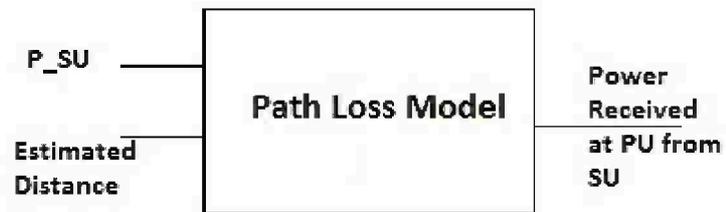


FIGURE 4.7: Path Loss Phase

[24]:

$$P_r = P_t K \left(\frac{d_o}{d} \right)^\gamma \quad (4.1)$$

Where,

- P_r is the received power at the receiver end.
- P_t is the transmitted power from the transmitter end.
- $K = \left(\frac{\lambda}{4\pi d_o}\right)^2$ which is a unitless constant that depends on the antenna characteristics and free-space path loss up to distance d_o .
- d_o is a reference distance.
1 m to 10 m indoor.
10 m tp 100 m outdoor.
- d is the distance between the transmitter and receiver.
- λ is the operating wavelength.
- γ is the path loss exponent (2 - 8).

4.2.4 Handover Decision Phase

Handover is necessary in one of two cases, either the interference on the PU's transmission becomes harmful or the QoS of the SU's transmission becomes not satisfying. Therefore, the handover decision depends on two parameters. The first one is the signal power (interference) received at the PU terminal from the SU which was estimated using the path loss model in the second phase. The second parameter is the spectral efficiency of the SU's transmission (SE_{SU}) as an indicator of the QoS.

As shown from Fig. 4.8, this phase consists of another FIS that takes two inputs (Interference and SE_{SU}) and results in two outputs. The first output, H , is a scalar value in the interval $[0,1]$ indicating the handover decision. If $H \leq 0.5$, then handover process takes place, while if $H > 0.5$, this means that handover is not necessary in this case. The other output, MOD ,

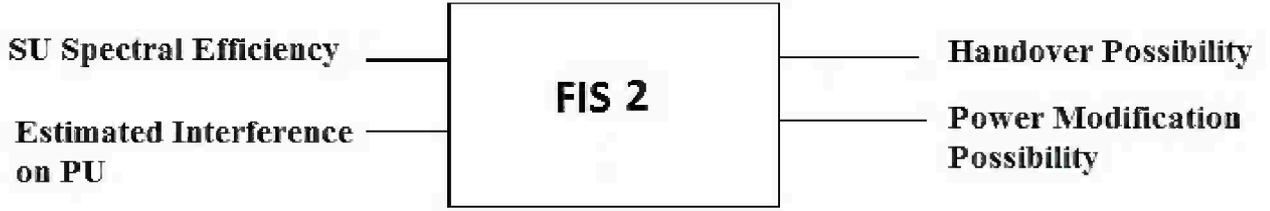


FIGURE 4.8: Handover Decision Making FIS

is a value also between 0 and 1, that indicates whether the transmitted power by the SU needs to be modified to avoid handover. The importance of this output appears when the QoS of the SU is satisfying and the interference on the PU is not high enough to force the SU to vacate the currently accessed channel. If $MOD \leq 0.5$ then power modification is necessary. Otherwise, no modification is required. However, it is worth mentioning that power modification will directly affect the spectral efficiency. Each linguistic variable is characterized, as in the first phase, by three sets (*Low*, *Medium* and *High*) except for the output (*H*) whose three sets are (*Yes*, *Probably Yes* and *No*). A Gaussian membership function is used for each set as shown in Fig. 4.9, 4.10, 4.11 and 4.12.

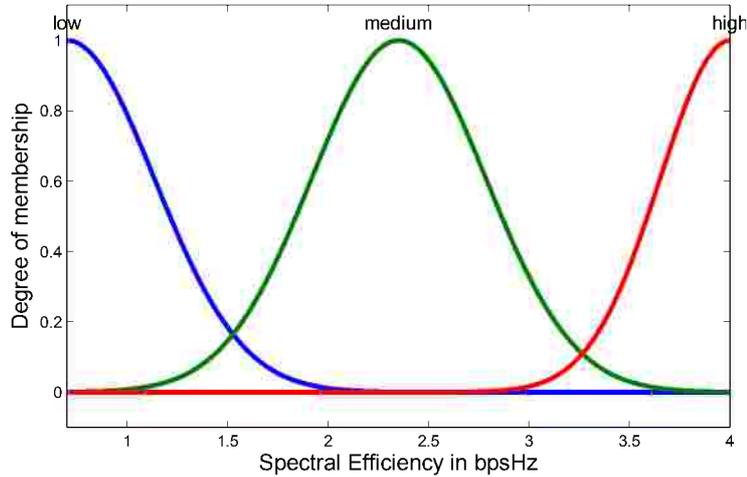


FIGURE 4.9: Membership Functions of SE_{SU}

IF-THEN rules that manage the relation between inputs and outputs in this phase are shown in Table 4.2. For instance, in rule 3, if the spectral efficiency of the SU is low and the interference over primary transmission is high, in this case, handover is necessary while power modification will not solve the problem. On the other hand, in rule 7, if the spectral efficiency

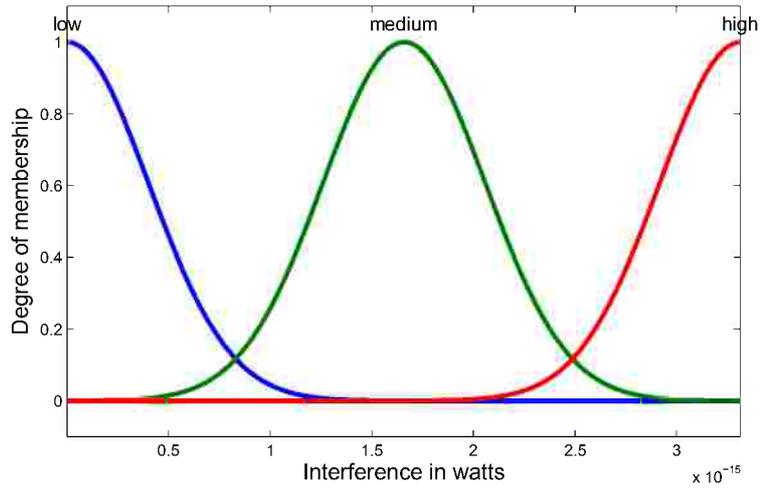


FIGURE 4.10: Membership Functions of The Interference On PU

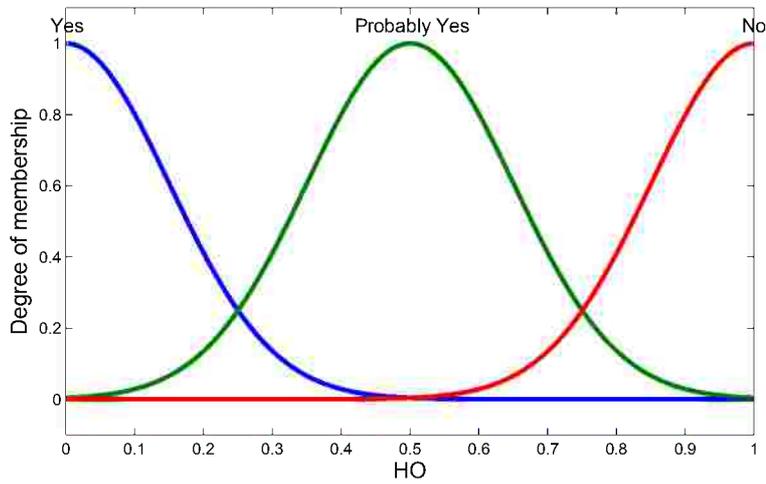


FIGURE 4.11: Membership Functions of The Handover possibility

is high and interference is low, there will be no need for handover nor power modification. The rest of the rules are obtained in similar manner.

Fig. 4.13 shows the fuzzy reasoning process.

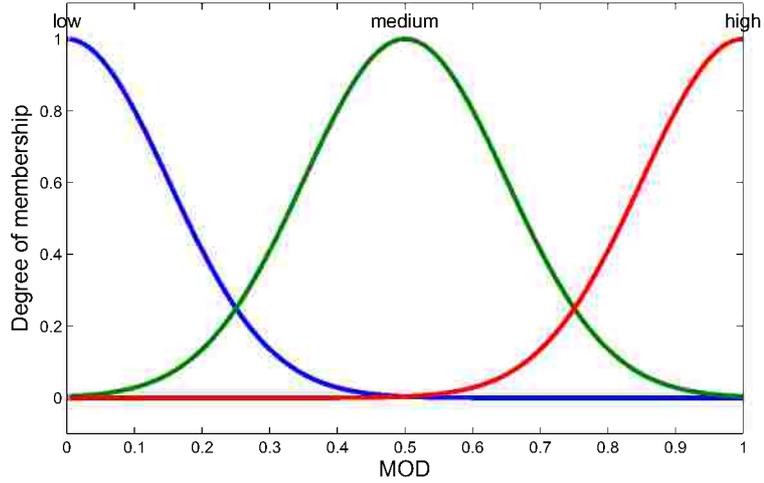


FIGURE 4.12: Membership Functions of The Power Modification possibility

No.	R_{SU}	Interference	H	PM
1	low	low	Probably Yes	low
2	low	medium	Yes	low
3	low	high	Yes	low
4	medium	low	No	low
5	medium	medium	Probably Yes	medium
6	medium	high	Yes	high
7	high	low	No	low
8	high	medium	Probably Yes	medium
9	high	high	Yes	high

TABLE 4.2: IF-THEN RULES of the Handover Decision Making FIS

4.3 Simulation Parameters

In this section, the main parameters of our model are indicated [3], [22], [24], [25], [26].

- **Primary User:** Digital (DVB-T) TV.
- **Secondary Network:** Wireless RAN.

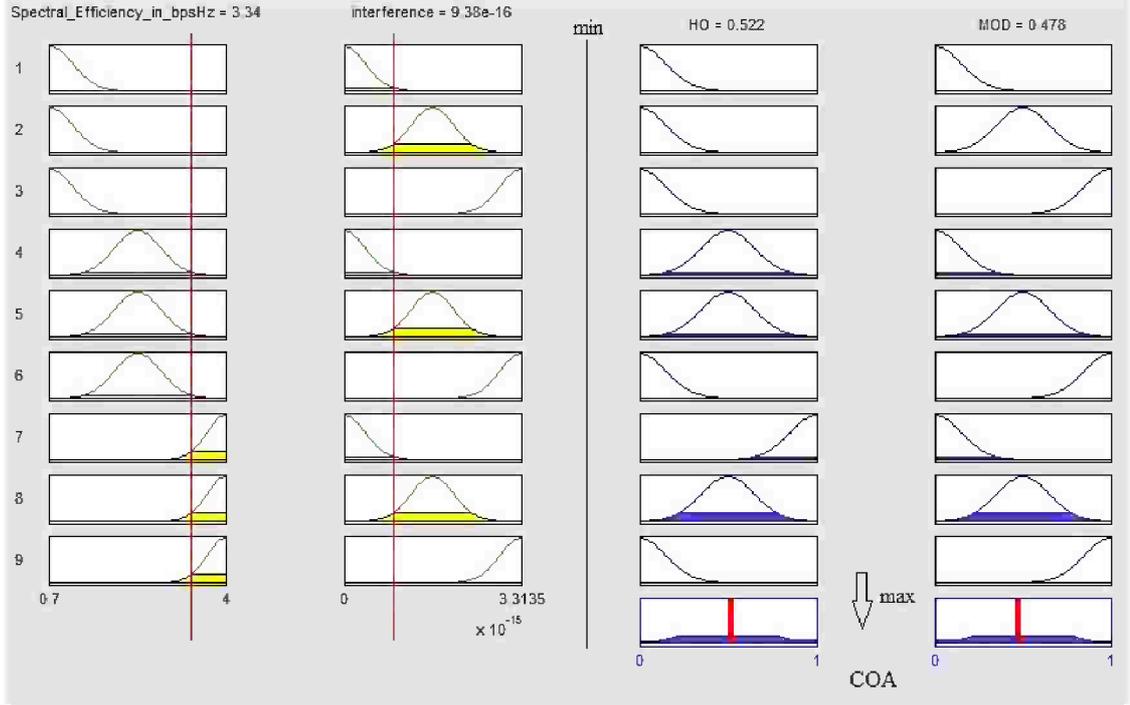


FIGURE 4.13: Fuzzy reasoning process of the handover decision making process

- **Path Loss Model:** Simplified Model as shown in detail in eq. 4.1. d_o is assumed = 10 meters and γ is chosen to be 4 [25].
- Numerical ranges of linguistic inputs to FISs are shown in Table 4.3.

Variable	Range
$R_{x_{PU}}$	-160 dBW to 40 dBW
SNR_{PU}	-5 dB to 30 dB
P_{SU}	0 dBm to 20 dBm
SE_{SU}	0.7 b/s.Hz to 4 b/s.Hz

TABLE 4.3: Ranges of Linguistic Variables

4.4 Performance Evaluation

MATLAB simulations were carried out using the *Fuzzy-Logic* toolbox. Performance evaluation in this chapter depends on two metrics:

1. Handover Percentage in case of existence of a PU.
2. Percentage of interference reduction on PU.

The two metrics are plotted versus the distance between the secondary nodes and the primary user. The presented fuzzy approach is compared to the case of *fixed threshold*. This later case doesn't adopt any fuzzy inference systems. It depends on comparing the spectral efficiency of the SU, SE_{SU} , and the interference on the PU to fixed thresholds and take the handover decision based on this comparison.

The handover percentage in case of PU presence is plotted in Fig. 4.14 versus the distance between PU and SU. As shown in the figure, handover percentage decreases as the distance increases which is logic because interference is reduced as the PU gets further from the SU. Handover percentage that results from the proposed fuzzy technique is less than the fixed threshold case which shows improvement due to the proposed method in this chapter.

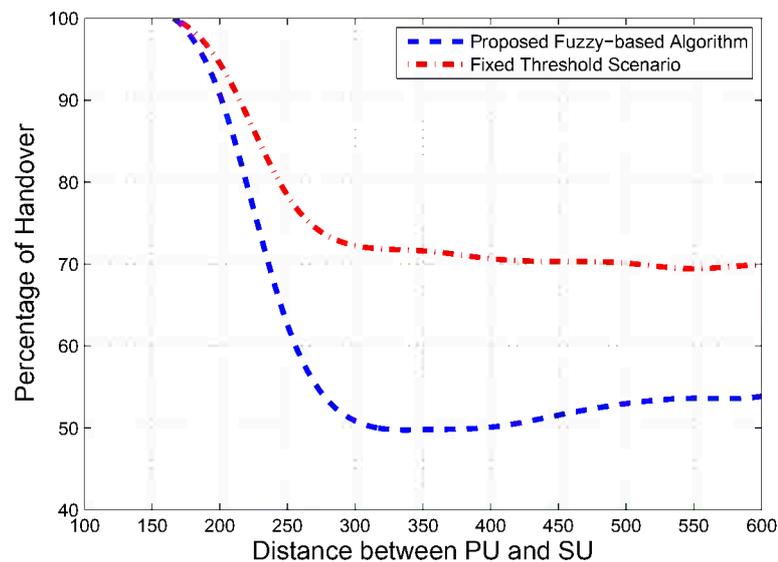


FIGURE 4.14: Handover percentage

Fig. 4.15 shows the percentage of interference reduction on the PU. Improvement in the reduction of interference due to the proposed technique is noticed.

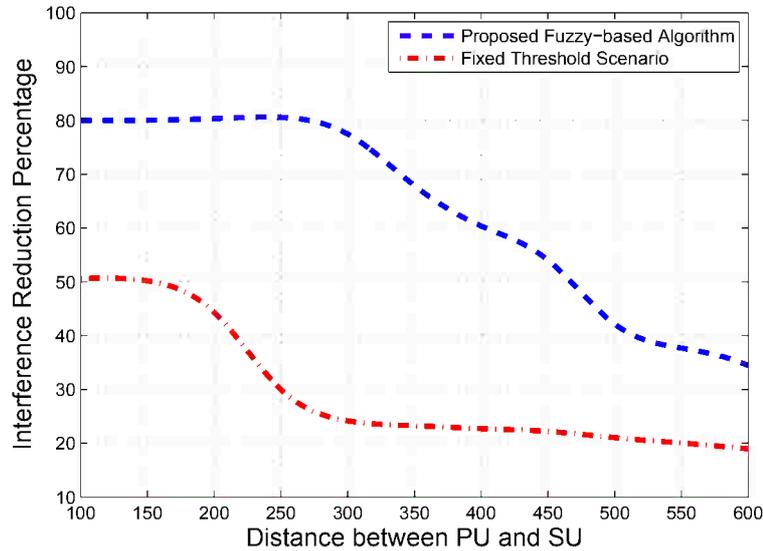


FIGURE 4.15: Interference Reduction percentage

4.5 Conclusion

This chapter presents a fuzzy based handover technique that is responsible for taking the decision of vacating the previously accessed channel by the secondary user and switching to another one. The proposed system, initially, checks whether the active user in the channel, if any, is a primary user or a secondary user. Afterwards, if a primary user exists, an algorithm consisting of three main steps is run to take the handover decision. The first step is a fuzzy inference system responsible for estimating the distance between the primary user and the secondary user. The second step estimates the interference that the secondary user causes on the primary transmission by applying an appropriate path-loss model. The last step is another fuzzy inference system that is responsible for the handover or power modification decision. The proposed technique proves enhancement in the handover percentage and the interference caused on the primary user. It outperforms the fixed-threshold case in which no fuzzy technique is applied and only a rigid comparison to threshold is considered.