Chapter 6
Application of Fuzzy Logic Power Control for Cognitive Radio Networks

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ABSTRACT

In this chapter, the authors present the application of fuzzy logic for power control in spectrum sharing cognitive radio network. The investigated network consists of a pair of primary users (PUs) and a pair of cognitive radio users (CRs). In order to compute an optimal power scale for the CR link, a fuzzy-based optimal power control strategy is investigated based on the Mamdani fuzzy control model using two input variables: the PU's signal-to-noise ratio (SNR) and PU's interference channel gain (channel gain from the cognitive radio users to primary users). Applying the fuzzy-based optimal power control strategy, the desired quality of service (QoS) is assured on the PU link, and the efficiency of spectrum usage is also maximized on the CR link in the spectrum sharing network. In addition, the bit error rate (BER) is also improved as compared with the spectrum sharing network without power control.

6.1 INTRODUCTION INTO THE NATURE OF FUZZY SET THEORY

We are accustomed to traditional tools of reasoning being strict and precise. In conventional binary logic a statement can be true or false, and there is no place for even a little uncertainty in this judgment. By studying the nature of sets, we can note that an element either belongs to a set or does not. We call these kinds of sets *crisp sets*. In practice we often experience those real situations that are represented by crisp sets, as impossible to describe accurately. If we assign a truth-value of 1 to the element that is included in the set, and a

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truth-value comparable to 0 to such an element that lies outside the set, then we will create the range of two-valued logic. This sort of logic assumes that precise symbols must be employed, and it is therefore not applicable to the real existence but only to an imagined existence.

If we consider the characteristic features of real world systems, we will conclude that real situations are very often uncertain or vague in a number of ways. If the information demanded by a system is lacking, the future state of such a system may not be known completely. This type of uncertainty has been handled by probability theories and statistics, and it is called stochastic uncertainty. The vagueness, concerning the description of the semantic meaning of the events, phenomena, or statements themselves, is called fuzziness (Zadeh, 1965; Zimmermann, 2002).

Let us thus yield the description of the concept of a fuzzy set, whose creator is Professor Lotfi Zadeh from Berkeley University. The crisp set A, established in the universe $X = \{x\}$, is characterized by a membership function $\mu_A : X \rightarrow \{0,1\}$. It means that $x \in A$ is related to A with the strongest truth degree equaling 1. Otherwise, element x does not reveal any connection with A when its membership is determined as 0. In fuzzy set theory this property is generalized. Therefore, in fuzzy set A, it is not necessary that either $x \in A$ or $x \notin A$ (Buckley & Eslami, 2002; Lowen, 1996; Pedrycz & Gomide, 1998; Rakus-Andersson, 2007; Zadeh, 1965; Zimmermann, 2002).

The generalization is assumed as follows. According to the above statement for any crisp set A it is possible to define a membership function $\mu_A: X \rightarrow \{0, 1\}$. In fuzzy set theory, the above membership function is generalized to a form that assigns every $x \in X$ a value from the unit interval [0, 1] instead of being assigned from the two-element set $\{0, 1\}$. The set A, defined on the basis of a generalized membership function, is called a fuzzy set. The membership function μ_A of fuzzy set $A \subset X$ is a function defined as μ_A: $X \rightarrow [0, 1]$. Every element $x \in X$ has thus *a membership degree* $y = \mu_A(x) \in [0, 1]$, which, via its value, provides information about strength of the relation between the element and the definition of the set. The fuzzy set A is finally completely determined by the set of pairs as $A = \left\{(x, y) = (x, \mu_A(x)), x \in X\right\}$. The important part of fuzzy set A is *a support* denoted by $\operatorname{supp}(A)$ and defined as a non-fuzzy set $\operatorname{supp}(A) = \left\{x \in X : \mu_A(x) > 0\right\}$. As imprecision of information is inserted into fuzzy sets then supports of sets closely defined create non-empty intersections.

6.2 BACKGROUND AND PROBLEM STATEMENT

Efficient use of the available licensed radio spectrum is becoming increasingly difficult as the demand and usage of the radio spectrum increases. This usage of the spectrum is not uniform within the licensed band but concentrated in certain frequencies of the spectrum while other parts of the spectrum are inefficiently utilized.

Among the efforts taken, by regulators worldwide, in order to achieve better usage of spectrum is the promotion of secondary markets. In a secondary usage context, the spectrum owned by the license owner, also called primary user (PU), can be shared by a non-licensee referred to as a secondary or cognitive radio (CR) user. The term Cognitive Radio was first introduced by Mitola in 1999 (Mitola & Maguire, 1999).

In cognitive radio environments the primary users are allocated licensed frequency bands while secondary cognitive users can be dynamically allocated the empty frequencies within the licensed frequency band, according to their requested quality of service (QoS) specifications. In this chapter we are interested in the spectrum sharing mode of cognitive radio systems (Kang et. al., 2009). In spectrum sharing, the PU and CR links utilize spectrum simultaneously. The CR link utilizes