Survey on Fuzzy Logic Enabled Cognitive Radios

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Abstract. Fuzzy Logic is an excellent method to incorporate for making decisions at various levels of cognitive radio under uncertain, incomplete and nonlinear environments. This is one of the most important methods to employ. It is due to the inherent characteristics of wireless channels that produce mostly inaccurate and incomplete information. Thus, the coexisting radios in a particular RF band have to make many decisions using incomplete information especially under cognitive radio access regime. This paper elaborates the concept of fuzzy logic and also investigates a review of the fuzzy logic in the domain of spectrum sensing, power control, resource management for cognitive radio applications. The survey presents the key applications as well as the benefits offered by this technology in comparison to the hard decision making logic i.e.1 and 0 for future wireless communications.

Keywords: Fuzzy logic · Spectrum sensing · Radio resource management Power control

1 Introduction

Fuzzy Logic is employed in various applications of wireless communications to improve decision making especially under uncertain and ambiguous situations and environments [1]. Fuzzy Logic based systems also find useful applications in smart control, decision analysis, signal classification, pattern recognition, transmission systems, and knowledge driven systems for optimization of power and computer vision. This technology converts the subjective knowledge into fuzzy logic that is used to drive systems.

Fuzzy logic introduces rule based system for incorporating human knowledge. Additionally, it can also be used by driving the fuzzy system through an intelligent algorithm such as neural network and evolutionary techniques [2].

Cognitive radio is an evolutionary technology that promises to fulfil imminent need of RF spectrum as part of the next generation 5G wireless systems [3]. This radio uses cognitive cycle to transmit over a white space (spectral hole) [4]. The cognitive cycle defines a set of principle steps that should be followed for successful exploitation of RF spectrum in secondary fashion. These steps include RF spectrum sensing, spectrum decision making and spectrum analysis. Additionally, various other sub steps are also

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required for successful utilization of RF spectrum in secondary fashion. The secondary access refers to the fact that the primary access of spectrum is related with the licensed access of the spectrum and the secondary access is related with unlicensed access. Spectrum sensing is the method of detection of RF spectrum bands for secondary access. This step can be employed through various detection algorithms including coherent and non-coherent techniques. The common algorithms which are extensively used include matched filter detection, cyclostationary feature detection and energy detection [5]. Various parameters are considered for selection of a detection algorithm. These include complete information about the primary user, complete information about the noise, partial or incomplete knowledge about primary transmitter or noise and no knowledge of primary user or its noise. Thus, selecting an algorithm is based on various factors. Hence, deciding to use an algorithm is also a problem based on incomplete information.

Classically, one algorithm is used extensively in the literature i.e. energy detector [6]. This method assumes the noise power of the primary environment is known in the absence of the knowledge about the primary user. However, this algorithm in practice cannot be applied to different signal detection scenarios. Hence, fuzzy logic driven decision making processor can be attached to the cognitive radio to help it in making better decision among usage of detector type based on received signal power, noise information and other information i.e. using under licensed band or unlicensed bands. Thus, performance of such a radio can be improved tremendously just by incorporating soft learning into the intelligent secondary radios. In addition to this example there are various other applications where fuzzy logic can be incorporated successfully to improve the performance of next generation radio systems.

The rest of the paper is organized as follows. Section 2 presents the application of fuzzy logic in transmits power control, spectrum sensing techniques, and spectrum analysis and spectrum decision process. Section 3 concludes the paper.

2 Fuzzy Logic Enabled Cognitive Radios

Decision making process finds vital role in the future 5G and 5G+ wireless communication systems. It is due to the changing role of mobile stations from least intelligent in classic 2G communications to the smart and intelligent radios in 4G and beyond. Thus, decision making in 5G radios can be incorporated through fuzzy logic based decision process. There are many key areas where fuzzy logic based radios can be exploited.

2.1 Spectrum Handoff Management

Spectrum Handoff is a channel switching process in which mobile station switches the cellular channel due to coverage or other reasons. For instance, at the boundary of a cell station, handoff process enables a user to continue a call in seamless fashion. It is also known as horizontal handoff. Another type, vertical handoff enables a mobile user to switch between two separate networks to enable the user to continue the active call. Typically, the handoff process is initiated once the received signal becomes weaker than a threshold. Two mechanisms can be enabled by a handoff user i.e. hard handoff and soft handoff. In hard handoff the mobile user disconnects its connection from a base station and connects to another. This feature is employed by 2G communication users. However, soft handoff communications exploited by CDMA users are connected with more than one base station.

In [7], authors use fuzzy logic based algorithm for handoff mechanism in indoor communications. Three parameters of interest are selected to decide the channel. These include received power, cellular user population and the bandwidth of each base station. The result of the proposed scheme is also considered with the classic power enabled handoff strategy. The results advocate the proposed scheme results in uniform population among various base stations. This equal load distribution among base stations results in better utilization of radio resources.

In [8], authors use various QoS parameters to decide regarding selection of a Base station using fuzzy logic based mechanism. The results are also compared with classical power based decision mechanism. The proposed scheme gives better selection of a network for the end user. Additionally, this method also results show an improved performance in the Quality of Service domain, in addition to avoiding repetitive switching among the networks. A QoS enabled fuzzy logic controller system is also proposed by authors in [9] for micro cellular mobile stations. In this system, authors introduce three input parameters for reliable fuzzy output. These include distance between mobile station and base station, received signal power and population on a specific cell.

In [10], authors propose a fuzzy logic based algorithm for handoff scheme that targets to get reduced packet-loss and probability of forced termination in addition to not increasing call-blocking significantly. This system also increases the system accuracy. Additionally, the proposed system provides reduction in location update cycle time.

In [11], authors propose a fuzzy logic based rule to involve a handoff mechanism in future heterogeneous networks. These networks are composed of other networks that include WAN, MAN, LAN and WPAN. Thus, seamless connectivity of a user passing through various wireless networks is an important task. In this paper, researchers also compute the accurate time of initiating a handoff through fuzzy logic. Genetic Algorithm (GA) is also involved in prediction of the rules for the proposed fuzzy logic based system.

In [12], authors propose a fuzzy logic based spectrum handoff algorithm that relies on several features that include received signal strength, traffic load of Base Station, path loss and signal to noise ratio. The proposed algorithm balances the traffic among Base Stations of the cellular network by selecting the best segment of the network. The simulation results show a remarkable improvement in the fair distribution of the load.

2.2 Spectrum Sensing

Spectrum sensing is a key step towards successful implementation of cognitive radio technology. This step enables a cognitive user to gather information about RF spectrum. Sensing can be performed locally as well as in cooperative fashion. Local sensing refers to the individual spectrum sensing performed by a sensor. The techniques for detection in local fashion include energy detection, cyclostationary detection and matched filter detection. In cooperative method, several users coordinate in sensing combining sensing results. This method is highly useful especially to combat hidden node issue in wireless communications [13].

This cooperation can be of two categories i.e. soft combining and hard combining. In soft combining method, complete sensing results are communicated to a fusion center (FC) that combines the results and computes final decision regarding presence or absence of a primary user. In hard combining approach, only one bit results i.e. 1 or 0 are transmitted to a FC that combines these bits to produce final decisions regarding presence or absence of a primary user in a given network. This benefit of improved results is achieved at the cost of cooperative communication overload among different sensing radios. Thus, to improve local spectrum sensing results, without bearing additional overload of cooperation, intelligent algorithms can be involved in spectrum sensing step to provide improved results. In such cases, fuzzy logic based controller can play a vital role.

In [14], authors propose a two-step spectrum sensing technique for improved detection of spectral holes in a cognitive radio network. In first step cognitive sensors detect the presence of primary activity through spectrum sensing algorithms i.e. energy detection, matched filter and feature detector. In the second step all the collected information is combined using fuzzy logic to produce improved decisions regarding presence of a primary user. The simulation results show that the proposed technique produces better detection probability and lower false alarm rate in comparison to the existing algorithms.

In [15], authors propose a fuzzy logic based cooperative spectrum sensing technique for improved detection results. This technique gets benefit of exploiting both cooperative features of the cognitive radios as well as fuzzy logic. Local spectrum sensing is performed through energy detectors. The sensing results are then combined using fuzzy logic system to produce final results regarding presence or absence of a primary user.

In [16], authors exploit the fuzzy logic approach in cooperative spectrum sensing radios to improve spectrum sensing efficiency in cognitive radio applications. This paper assumes the cooperative nature of local sensors to combine the sensing results using selection combining and maximum ratio combining by incorporating fuzzy logic based system. Fuzzy system is introduced to evaluate the energy of sensing radios. This method helps in avoiding the use of channel state information that is essentially required to compute local spectrum sensing algorithms. Additionally, the results of the proposed method suggest an improvement in terms of sensing accuracy.

In [17], authors use cooperative spectrum sensing technique for detection of free spectral slot. An additional benefit of the proposed system is employing trust of local sensors that take part in local spectrum sensing process. Thus, trust established by the sensors is incorporated in computing decisions regarding presence or absence of a primary user through fuzzy logic based system. The computed results show improved performance in comparison to the classical spectrum sensing techniques for cognitive radio applications.

In [18], authors integrate the HMM algorithm with fuzzy-C means clustering to devise an efficient model for the prediction of RF spectrum in Cognitive Radio networks. The simulation results suggest that the proposed technique works better even under higher percentage of failure of secondary users in the cognitive radio network environment.

2.3 Power Control

Power control in wireless communications is a challenging task. By transmission of data over higher power can cause harmful interference to the other users of the network in addition to creating many other issues. However, transmission of data over low power will not close the wireless link. Additionally, power control mechanisms have more important role in cognitive radio applications as well. It is because the cognitive radios are secondary radios and they have to transmit over controlled levels of transmission power. Because, in case these radios transmit over higher transmit powers, the primary radios will be highly affected due to the interference from these radios. In such cases, transmit power control methods will be highly important for future cognitive radio applications.

In [19], authors consider the power control scenario by establishing a cognitive radio secondary network through low power radios that coexists with primary network. The proposed network can work simultaneously without creating any harmful interference to the primary activity as per the guidelines of Federal Communications Commission (FCC). The proposed setup helps in maximizing energy efficiency of secondary network with an added benefit of guaranteed-QoS for both primary and secondary users. Authors also derive the solutions for centralized and distributed setup. Additionally, a joint power and admission control techniques are also provided so that the priority of primary activity shall always be ensured. The simulation results of the proposed technique show the effective utilization of power in secondary users can improve efficiency of radios significantly.

In [20], authors present a theoretical framework for power allocation techniques in cognitive radio applications. The key goals in designing any power control algorithm include QoS protection to licensed activity, opportunities for secondary activity, admissibility of secondary users into primary network and autonomous operation of individual users. Additionally, two more goals which are required rather than mandatory are also considered. These include licensing and adaptability. Furthermore, a duo priority (DPCPC) driven policy is also presented that satisfies the required goals. The performance of the proposed setup results in improved performance in interference-aware paradigm over classical methods of operation in power control mechanisms.

In [21], authors present a power control mechanism for cognitive radios under uncertain channel conditions. Typically, the channel between primary user and the cognitive sensor is unknown. In this paper, authors consider both small scale fading and lognormal fading scenarios. Additionally, authors also introduce uncertainty into the system by considering the fact that primary user is not active all the time. It may switch on and off during the complete cycle of activity. Furthermore, centralized network utility maximization (NUM) problems are presented and solved through sequential programming. Authors also consider a specific case where the channel between two secondary users is considered as uncertain. For such network, outage probability is also computed.

3 Conclusion

A survey of fuzzy logic enabled techniques for future cognitive radios is presented. The applications selected for the purpose are power control, spectrum sensing and handoff management. This investigation summarizes the achievements of several authors in this area. As the incomplete information gathered by the wireless sensors create a hurdle in decision making process, the fuzzy logic enabled techniques can perform faster as well as more reliable. The presented techniques may take a fair portion of the Cognitive Radio equipment in the future generation of wireless radios.

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