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Various Techniques for Controlling Transmit Power in Cognitive Radio: A Survey

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Abstract- Cognitive radio has been recently proposed as a promising technology to improve the spectrum utilization efficiency by intelligently sensing and accessing some vacant bands of primary users (PU). After reviewing fundamental papers it is found that much work has been done in the field of spectrum sensing for cognitive radio and different types of spectrum sensing methods. Transmitted power of CUs causes interference to PU when it is beyond tolerance limit. Most of this area has been remained untouched. This paper focuses on the work done in controlling the transmit power. In this situation, an effective and appropriate power control method is necessary for cognitive users for achieving quality of service (QoS).

Keywords- *Cognitive Radio Networks, Underlay Spectrum Sharing, Interference, Power Control, Game Theory, ANFIS.*

I. INTRODUCTION

Recently, the demand for wireless networks resources is exponentially increasing over the world. As the wireless applications are increasing very fast, the radio spectrum resources are becoming more congested. In wireless networks, there are limited resources that can be used by different users for their data transmission to achieve their requirements of quality of service (QoS). The limitation of the available resources and the increment of the demands of these recourses lead to spectrum scarcity problem [1, 2]. However, some researches show that spectrum resources of partial licensed frequency have not been fully utilized, so there is “spectrum hole” in time and space. To overcome spectrum scarcity problem, Federal Communications Commission (FCC) has already started working on the concept of spectrum sharing [3]. In spectrum sharing the spectrum could be shared between both unlicensed (secondary users, SUs) and licensed (primary users, PUs) users, provided the SUs respect PUs rights to use the spectrum exclusively [4, 5].

Cognitive technology is considered as a promising technology for spectrum exploitation dynamically. By integrating the capability of the cognitive technology in the traditional wireless networks, the spectrum scarcity problem can be solved. The main functions of cognitive radio are spectrum sensing, spectrum management, spectrum sharing, and spectrum mobility [6, 7]. Nowadays the main research topic in cognitive radio networks is spectrum sharing and power control considering the threshold constraint. To make full use of the spectrum resources, the concept of opportunistic spectrum access is necessary for CR [8]. When cognitive users dynamically access licensed spectrum, whether it will interfere with the primary user should be particularly considered. In this situation, an effective power control method is necessary for cognitive users. In addition, appropriate power control strategies are essential for achieving both quality of service (QoS) and system capacity objectives. When the primary user is close, the cognitive user should change its power to avoid high interference or leave the channel at the worst condition.

In addition, the game theory applied in economics is also used to solve the problem of power control. Based on a suitable utility or cost function, the effective iterative function will be obtained as cooperative or non cooperative power control algorithms. The power control solution used in the CR system considers not only the QoS of cognitive users but also interference with primary users. Here we are presenting a new non cooperative power control algorithm. Game theory has been proved to be an effective method to solve the power control problem. Our intent is to import power threshold to iterative algorithm by using game theory in cognitive networks. Most of solutions using game theory focus on the change of SINR [9]. However, power threshold is the main point in cognitive networks, so we attempt to propose a new solution based on the power limit. In addition, we try to discuss how the cognitive users should act in volatile power limits. If cognitive users cannot satisfy the SINR requirement when lowering their power, they shall make a choice between changing their positions and leaving the channel. Due to the characteristic of the SINR and our power algorithm, users do not need additional information from the base station (BS), which will reduce the complexity of the system.

The rest of the paper is organized as follows, Section I contains the introduction of the topic, Section II contain the literature survey and the work done in this area, Section III compares the various techniques and conclusion is presented in Section IV.

II. LITRATURE REVIEW

In [10], Wang Xia and Zhu Qi (2007) have studied the power control in cognitive radio system and used game theory for modelling. Non-cooperative power control game created by D. Goodman had been used. Price-based power control problem in the spectrum sharing cognitive radio networks had been investigated. The sigmoid based NPGP (non cooperative power control game with pricing) algorithm for controlling the transmitter power had been introduced.

In [11] Karama Hamdi et al. (2007) had considered the case of a primary user and a cognitive radio sharing spectrum. For controlling the interference to the primary user, while maintaining a quality of service for the primary user, they have developed a power control technique which controls the transmit power of the cognitive radio. Numerical results showed that the proposed technique can guarantee QoS. In [12] Luyong Zhang et al. (2009) represented the distributive power control technique in cognitive radio system based on the CDMA. The proposed SANGPC algorithm can converge fast and provided low average power. The results clearly showed that this technique can adapt the SIR according to different SIR requirement. By compromising SIR and power, the convergence speed can be improved.

In [13] Zeljko Tabakovic et al. (2009) had presented alternative transmit power control strategy for cognitive secondary users by using opportunistic spectrum access. By using fuzzy logic system, transmit power was controlled in simple and low cost implementation of transmit power control (TPC) function. While minimizing the interference to primary user, cognitive users had achieved required transmission rate and quality by using TPC technique. By using this technique, smaller interference potential and reduction of frequency reuse distance was achieved. In [14] Ping Li et al. (2010) had proposed a new power control algorithm in a cognitive radio system with MC-CDMA. A novel non-cooperative power control game (NPCG) algorithm on the basis of SIR had been proposed. The new algorithm fulfilled requirements of various users' SIR and increase system's throughput. The simulation results showed that Koskie-Gajic algorithm only pays attention to control transmit power, but neglects real requirement of users' QOS. In the cognitive radio, SIR balancing algorithm focused users' QOS, but ignored the overall performance of the system. But it had been proved that the new algorithm not only satisfies requirement of the different kind of SIR, but also improves system's throughput and efficiently control user transmit power. In [15] Chen Sun et al. (2010) proposed an adaptive-power-control technique for a cognitive radio system (CRS) in a Rayleigh fading channel. To maintain a constant output SNR to the cognitive radio user receiver by allowing transmitted power adaptation at the cognitive radio user transmitter to, the output SNR was maximized in this technique and interference is limited to primary user at a tolerable level. An investigative replica for the distribution of the interference to the PU while allowing for the detection presentation at the SU was developed and hence by using this the constant output SNR at cognitive radio user was obtained. In [16] Ai Wei Sun and Hang Zhang (2012) proposed a power control algorithm with a pricing factor. It had been stated that the NPGP (non cooperative power control game algorithm with pricing) algorithm can solve the power control problem of the cognitive radio system. The simulation result also proved that the proposed algorithm can improve the performance of the cognitive radio system and decrease the interference among the cognitive radio users. It had been proved that the utility function value of the user decreases with the distance between the user and the based station increasing. The utility value of the user in the NPGP model was bigger than the NPG algorithm without a pricing factor. In [17] Siamak Sorooshyari et al. (2012) represented the first axiomatic approach to power control in cognitive radio networks. Four attributes (QoS protection, opportunism, admissibility, autonomous operation) as these are essential of a power control scheme deployed by users in a cognitive radio network had been proposed. An axiomatic approach of how a general class of Duo Priority Class Power Control (DPCPC) policies can protect primary users from the entrance of secondary users, provided opportunism to secondary users, and prevented the most adverse types of admission errors is presented. Autonomous Interference-aware Power Control (AIPC), which belongs to the general class of DPCPC policies, had been proposed. In [18] Chen Sun et al. (2012) stated the two types of coexistence in wireless networks. One is coexistence between cognitive radio user networks and other is coexistence between primary user and cognitive radio user networks. In first type of coexistence the main concept was sharing a common spectrum resource among cognitive radio user networks to achieve an optimal spectrum utilisation, whereas in the second type of coexistence the interference from cognitive radio users to Pus is considered. The effective strategies to utilise the spectrum in efficient way by maintaining the coexistence among the users had been discussed. In [19] Zhengqiang Wang et al. (2013) had proposed a novel price-based power control algorithm in CDMA-based Cognitive radio networks. The base station (BS) of primary users (PUs) can allow cognitive users to access if interference caused by them was under the interference power constraint (IPC). To access the spectrum, cognitive users had to pay for their interference power. The BS first decided the price for each SU to maximize its revenue. Then, to increase its revenue each cognitive radio user controlled it's transmit power to based on non-cooperative game. Numerical results proved that the proposed pricing algorithm enhances the revenue of both the BS and cognitive radio users compared with the proportionate pricing algorithm. In [20] Zhao Junhui et al. (2013) formulated a Non-cooperative Power Control (NPCG) game model for spectrum sharing model of CR network, and used mathematical analysis method to prove the existence of the uniqueness of NE. By using NPCG algorithm, requirements of QoS and convergence in small number of iterations can be achieved. The power value of the proposed algorithm was lower than that of the Nash algorithm, but their SINRs meet the threshold. In both algorithms SINR threshold requirement can be achieved, but the power value of the Nash algorithm is much higher than that of the proposed algorithm. In Nash algorithm, the iteration times to convergence was more than that of proposed algorithm. In [21] Lu Lu and Geoffrey Ye Li (2013) had investigated optimal power allocation schemes for underlay CR networks with both direct and relay-aided transmissions. They provided the theoretical analysis of overall rate optimization problem in CR network while interference to the PU is considered under the acceptable level and keeping the peak power to each node under the tolerable level. After considering fair power allocation between two CR users they further addressed the overall rate optimization problem with an additional sum power constraint and got the favourable results between two CR users by adjusting the sum power threshold. A power allocation scheme which can be used to choose best relay in a multi relays system, had been proposed. In [22] Mardeni R et al. (2013) describe the basic concepts of cognitive radio and fuzzy logic. An algorithm to optimizing the power consumption and spectrum handoff rate of cognitive radio had been proposed. Main focus was on spectrum handoff where secondary user can returns the spectrum to demanded primary user. It had been discussed that cognitive user can adjust its transmission power without disturbing the transmission of primary user instead of choosing spectrum handoff. It had been stated that if secondary user cannot change transmit power within tolerable limits then only it will switch between different bands. The limitation of the proposed algorithm as the average transmission power of secondary user in their algorithm was more as compared to the reference algorithm, was discussed. But on the other hand, proposed algorithm guarantees a low spectrum handoff rate which leads to low processing cost of their algorithms as compared to reference algorithm. In [23] Joyraj chakraborty et al. (2013) proposed ANFIS based opportunistic power control technique by considering primary user's SNR and primary user's interference channel gain as inputs. It had been stated that proposed strategy shows better performance than the one without power control. Cognitive radio is the solution of spectrum scarcity problem. However, cognitive radio was not allowed to interfere with the primary user communication in any condition. So It had been proposed that power management can be done without interfering primary user. The future aspects of their work that the proposed strategy can be extended to the infrastructure with multiple primary users and multiple cognitive users so that each cognitive user will have a choice to select the best primary link, to improve the spectrum utilization, had been discussed.

In [24] after studying several powers control algorithms based on different cost functions, Yousef Ali Al-Gumaei et al. (2014) proposed a novel cost function that consists of a weighted sum of power and square function of SIR error based on sigmoid function. In the proposed sigmoid based power control algorithm reduction in power at approximately the same level of average SIR is achieved. By using this algorithm more number of CRs can be served and hence optimal exploitation of the spectrum with the least amount of interference is achieved. In [25] as the wireless applications are increasing worldwide on large scale, the spectrum resources are becoming more and more congested. Now a days it is very crucial task to effectively utilise the spectrum resources as more number of applications to be served without disturbing the transmission of others. Cognitive Radio is evolving technology that manages spectrum more efficiently by allowing non-licensed users to with dynamism access to the same. In this paper Jadhav Priyanka D. and Dr. Kanse Y.K (2015) provided the literature survey and the previous work done in the development of power control in cognitive radio networks. By reviewing some fundamental papers in this area, the merits and demerits of power control techniques and explained the basic mechanisms of efficient power control schemes had been mentioned. In [26] Nandkishor Joshi and Bhavana Jharia (2015) proposed an ANFIS based power control technique to improve the performance of the secondary user by maintaining the QoS to the primary link and minimize the bit error rate in the cognitive radio networks. It had been proved that by using this technique the bit error rate is smaller than that of without using power control technique. The system used i.e. adaptive neuro-fuzzy inference system was based on sugeno fuzzy management model by considering two input variables: SNR of primary user and interference channel gain. It had been concluded that ANFIS can be used for power management in cognitive radio by improving the performance of the secondary user. It was depending on user's demand or model style and human skilled information that whether to use ANFIS or FIS. But by using ANFIS, efforts were minimized, and it will learn and adapt from the atmosphere.

III. COMPARISON

Table: Comparison of All the Previous Work Done

Author	Year	Technique used	Result / Inference
Wang Xia and Zhu Qi	2007	Sigmoid based NPGP (non cooperative power control game with pricing	It provided the lower transmit power but utilities are also larger. It gave better result comparing to NPG and NPGP used in traditional CDMA systems.

Karama Hamdi et al.	2007	Spectrum sensing side information	Transmit power was controlled. It guaranteed a reliable QoS for PU in any location while enhancing the spectrum utilization greatly.
Luyong Zhang et al.	2009	Distributed power control technique SANGPC	Converged fast and provided low average power, can adapt the SIR according to different SIR requirement. By compromising SIR and power, the convergence speed can be improved.
Zeljko Tabakovic et al.	2009	TPC technique using fuzzy logic system	Transmit power was controlled in simple and low cost implementation of transmit power control (TPC) function. If interference was minimized, CU achieved required transmission rate and quality by using TPC technique.
Ping Li et al.	2010	Novel non-cooperative power control game (NPCG) algorithm on the basis of SIR	The proposed algorithm not only satisfied requirement of the different kind of SIR, but also improved system's throughput and efficiently control user transmit power.
Ai Wei Sun and Hang Zhang	2012	Algorithm with a pricing factor. NPGP (non cooperative power control game algorithm with pricing)	Transmit power is controlled and the utility value of the user in the NPGP model was bigger than the NPG algorithm without a pricing factor.
Zhengqiang Wang et al.	2013	Novel price-based power control algorithm in CDMA-based Cognitive radio networks.	To access the spectrum, cognitive users had to pay for their interference power. The BS first decided the price for each SU to maximize its revenue. Then, each cognitive radio user controlled it's transmit power to maximize its revenue based on non-cooperative game. The proposed pricing algorithm improves the revenue of both the BS and cognitive radio users compared with the proportionate pricing algorithm.
Zhao Junhui et al.	2013	Non-cooperative Power Control (NPCG)	The power value of the proposed algorithm was lower than that of the Nash algorithm, but their SINRs meet the threshold. In Nash algorithm, the iteration times to convergence was more than that of proposed algorithm.
Mardeni R et al.	2013	Efficient Handover Algorithm Using Fuzzy Logic Underlay Power control for Cognitive Radio Wireless Network	They discussed that cognitive user can adjust its transmission power without disturbing the transmission of primary user instead of choosing spectrum handoff. Proposed algorithm guarantees a low spectrum handoff rate which leads to low processing cost of their algorithms as compared to reference algorithm
Joyraj chakraborty et al.	2013	ANFIS based opportunistic power control technique	Proposed strategy showed better performance than the one without power control.
Yousef Ali Al-Gumaei et al.	2014	New SIR-Based Sigmoid Power Control Game algorithm	In the proposed sigmoid based power control algorithm reduction in power at approximately the same level of average SIR was achieved. By using this algorithm more number of CRs can be served.
Nandkishor Joshi and Bhavana Jharia	2015	ANFIS based power control technique	Optimized fuzzy power control over fading channels using ANFIS. Proposed technique improves the performance of the secondary user by maintaining the QoS to the primary link and minimizes the bit error rate in the cognitive radio networks. It had been proved that by using this technique the bit error rate was smaller than that of without using power control technique.

IV. CONCLUSION

This paper depicts of the development of various techniques of power control in cognitive radio networks and discussed the merits and demerits of various power control techniques. After reviewing some fundamental papers in this area, it is concluded that the main two parameters transmitted power and SNR of CUs are contradictory to each other. If SNR is improved then it is required to increase the transmitted power or reduce the noise. Noise is AWGN noise. So the only remaining parameter is transmitted power of CUs. But also transmitted power cannot be increased beyond a limit because it will create interference to primary user (PU). To maintain the transmitted power threshold at PU, it is necessary to have lower power values. So it is a compulsion here that one cannot neither decrease the power value nor increase the SNR. In all the reviewed papers one parameter is increased on the cost of other. In this way, vision of the large picture for the subareas discussed, including some important aspects of power control algorithms that could accelerate the deep familiarization with the area. Numerical results of the papers show that the quality of service for the licensed user can be guaranteed in the presence of the cognitive radio by the approach proposed in the reviewed papers.

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