An Efficient Power Control Algorithm for Supporting Cognitive Communications in Shared Spectrum Areas

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Abstract. The concept of *Cognitive Radio (CR)* is meant to be utilised by both licensed and license-exempt users that coexist in a shared spectrum area whenever they need to avoid causing unaffordable interference to each other by following some rules. In fact, primary users should be protected by any license-exempt transmission. To this end, power control is a pivotal mechanism to be used for interference management in these scenarios. Especially, transmit power control is a vehicle to mitigate interference, in presence of CR technology, when primary receivers are attempting to reach a desired *Signal-to Interference Noise Ratio* (SINR) level. In this work we assume that a CR network relies on the same spectrum area with a primary network. Our scope is to measure the introduced interference level caused by the CR transmitter and to properly modify its power to allow a legacy user to reach a required SINR according to location of the primary user in presence of interference. A series of results are presented to prove the efficiency of our proposed scheme.

Keywords: Power Control, Primary Users, License-exempt, Shared spectrum.

1 Introduction

In modern wireless communication systems, the number of wireless users is steadily increasing resulting to a necessary demand for more available radio spectrum. Most of the radio frequency spectrum bands are completely assigned to certain technologies and it is becoming hard to find new vacant spectrum bands to deploy new technologies or enhance the existing ones. Measurements in [1] reveal that up to 85% of the spectrum available areas are partly occupied or completely unoccupied at a given time and location. Therefore a more flexible allocation strategy could solve the spectrum scarcity problem.

The concept of *Cognitive Radio* (CR), which firstly coined by Mitola in [2], is one of the most suitable solutions to support scenarios where primary users coexist with license-exempt users at the same spectrum and location area. In this case, primary users have to be protected from any potential harmful interference caused by secondary networks. If no guarantees are provided about this, it will be hard to convince a primary user to be connected to a primary network in presence of a license-exempt radio network. However, if the latter is based on a CR technology, interference and capacity requirements about the primary user can be satisfied.

Therefore one of the most challenging issues within the context of the CR technology is to provide the prospective primary users with guarantees about the interference and the channel's capacity that is in line with Ofcom's SURs (Spectrum Usage Rights) concept [3]. In addition, due to its spectrum sharing nature, a CR network inevitably operate in interference intensive environment and effective interference management is essential towards the mitigation of interference mainly at the side of the primary user. *Power Control* is one of the most known techniques utilised to accomplish the aforementioned goal.

Our interest in this paper lies within area of the interference mitigation at the edge of the primary network to reach a desired *SINR* level in order to support adequate Quality of Service (QoS) level, by adapting the power of the CR transmitter. The cognitive network locates in the antenna effective area of the primary network and it is not possible to avoid producing interference to the primary network. To this end, the CR transmitter that is capable of measuring the current interference at the primary network, it adjusts its transmission power to avoid harmful interference to the primary user and to acquire the appropriate channel capacity users.

This paper is structured as follows. In section 2, we discuss related work done in the area of power control. In section 3, we present the model that has been assumed in this paper. In section 4, we proposed our power control algorithm and examine the different parameters such as SINR, interference, path loss and channel capacity seen by primary user in case of a fixed size licensed spectrum network. In section 5, mathematical and simulation results are presented. Finally, in section 6 we conclude this paper and we mention ideas for future work.

2 Related Work

In [4], author presents an optimal power control method to maximize the secondary user ergodic capacity subject to a new proposed constraint to protect the primary transmission, which limits the maximum ergodic capacity loss of the primary user resulted from the CR transmissions. The fundamental capacity limits for spectrum sharing based CR networks over fading channels are studied by the author. Results reveal that the proposed policy can lead to substantial capacity gains for both the PU and SU over the conventional policy.

The light of [5], authors present a mathematical model for calculating the total unexpected by any primary receiver interference in the presence of CRs. In that work, cumulative distribution function (CDF) of the interference due to the cognitive devices is calculated meanwhile primary protected area and number of the deployed cognitive radios is computed. The results reveal if CRs have a priori knowledge of the radio environment map, the number of CRs deployed in that environment can be increase.

In [6], authors present a novel hybrid power control scheme in an Hierarchical Spectrum Sharing Network (HSSN) to fully make use of the potential of an HSSN. The proposed scheme is composed of a centralized power control scheme, a distributed power control scheme and a coordination policy to coordinate these two types of power control schemes when both of them are exploited in the same channels. Outcomes of the paper reveal that the proposed power control scheme can meet the requirements of low emission power as well as high QoS level.

3 System Model

The configuration of our system is shown in Figure 1. We consider a primary system that is surrounded by a CR network. The primary receiver is placed at the edge of the primary network and its transmitter in the centre of a circular region of radius R. As shown in Figure 1, within the protected area there is not interference and the primary users satisfy a SINR value to transmit data to the base station *(SINR>SINRt)*.

$$\sum_{\substack{j=1 \\ i\neq j}}^{M} P_{ij} h_{ij} \le I_t \tag{1}$$

The path gain h_{ij} is given by [6]

$$h_{ij} = {d_{ij}}^{-\alpha} 10^{\tau/10} \tag{2}$$

The threshold interference (I_t) in general may depend on the characteristics of the interfering signal (e.g. signal waveform, continues vs. intermittent interference).

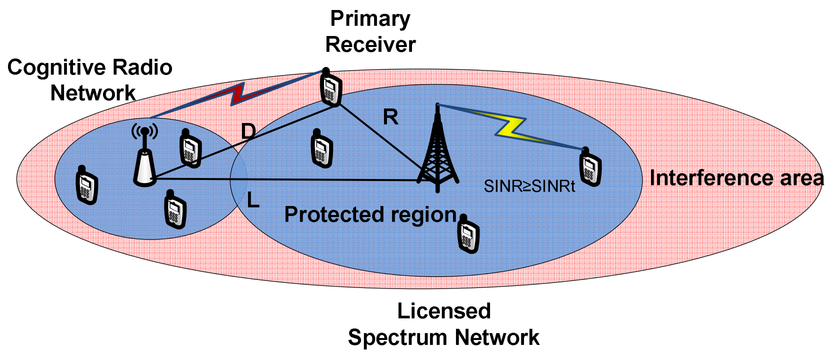

Fig. 1. Our scenario where the primary and the secondary network use the same spectrum band.

The interference range depends on the CR transmitter's power and the primary receiver interference tolerance. The interference range and minimum distance between the CR transmitter and the primary receiver can be calculated as follows:

$$Dmin = (P_c 10^{\frac{\tau}{10}} / I_t)^{1/\alpha}$$

Table 1. Definition of parameters

P_{ij}	Transmitted power of transmitter *i* to receiver *j*
h_{ij}	Path gain between transmitter *i* and receiver *j*
α	Path loss factor
τ	Random variable of normal distribution
σ^2	Background noise
h_{kj}	Path gain between transmitter *k* and receiver *j*
I_t	Minimum interference that primary user can tolerate in channel *j*
d	Distance between transmitter *i* and receiver *j*
M	Number of transmitter
$SINRt$	Necessary SINR to support QoS

The first goal of this work is to mitigate the harmful interference caused by the CR transmitter to the primary users. It is required that the total transmitted power of the CR should not exceed an interference constraint.

The received power by the primary user should be written as:

$$Pr = Pt.d^{-\alpha}10^{\tau/10}$$

Where Pt denotes the power of the transmitter (license-exempt user). Consequently, the interference to the primary user should be:

$$I_p = \sum_{\substack{j=1 \\ j\neq i}}^{M} d_{ij}^{-\alpha} P_j 10^{\tau/10}$$

The second scope of this work is to optimize the primary user's QoS level based on its position. Considering the SINR requirements as the basic QoS metric, the received SINR must exceed a desired threshold in order the legacy user to recover correctly the received data. We define *SINRt* the minimum value at which the primary receiver has the minimum required QoS level to support is communication link. Thus, the SINR of the primary user *i* could be expressed by:

$$SINR_i = \frac{P_{ij}h_{ij}}{\sigma^2 + \sum_{\substack{k=1 \\ k\neq i}}^{M} P_{kj}h_{kj}} \geq SINRt \qquad (3)$$

Moreover, the value of the channel capacity indicates the level of the QoS at the side of the primary user and can be expressed by:

$$C = B \log_2(1 + SINR) \text{ bps}$$

To achieve the required SINR and the QoS level of the primary receiver's communication link, a nonlinear program can be satisfied the requirements as follows:

$$\text{Maximise } SINRi = \frac{P_{ij}h_{ij}}{\sigma^2+\sum_{\substack{k=1\\k\neq i}}^{M} P_{kj}h_{kj}} \geq SINRt$$

$$\text{Subject to} \begin{cases} \sum_{\substack{j=1\\i\neq j}}^{M} P_{ij}h_{ij} \leq I_t \\ 0 < P_c \leq P_{cmax} \end{cases} \quad (4)$$

4 Proposed Methodology

In this section, we mathematically calculate the SINR and the channel capacity at the licensed user. Our solution is based on the position of the primary user and the CR transmitter. In this scenario the CR network attempts to utilize the spectrum thus causing harmful interference to the primary user. We assume the primary network's base station as highlighted in Figure 2. The position of the primary user each time can be expressed by:

$$\Delta = r\measuredangle\theta, \text{ Then } \Delta_x = rcos\theta, \Delta_y = rsin\theta$$

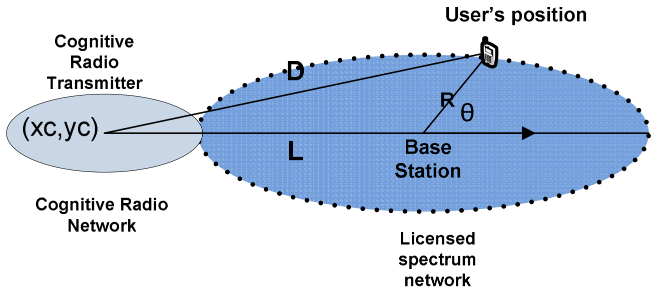

Fig. 2. Mathematic and geometric explanation of the system model.

$$D = \sqrt{\left((x_c - \Delta_x)^2 + \left(y_c - \Delta_y\right)^2\right)}$$

Getting D into equation (2)

$$h_{cp} = (\sqrt{\left((x_c - \Delta_x)^2 + \left(y_c - \Delta_y\right)^2\right)})^{-\alpha}10^{\tau/10}$$

Where h_{cp} denotes the *path gain* between the primary receiver and the CR transmitter. By recalling the SINR formula at the primary receiver:

$$SINR_p = \frac{P_{BS}R^{-\alpha}10^{\tau/10}}{\sigma^2+P_cD^{-\alpha}10^{\tau/10}} \quad (5)$$

The minimum SINR occurs when $D = Dmin$ namely θ is equal to:

$$\frac{\partial D}{\partial \theta} = 0 \implies \theta = -\tan^{-1}(\frac{y_c}{x_c})$$

The adjusted power of the CR due to *SINRt* of the primary user is given by:

$$P_c = (\frac{\left(P_{BS}R^{-\alpha}10^{\frac{\tau}{10}}\right)}{SINRt} - \sigma^2)D^{\alpha}10^{-\tau/10} \quad (6)$$

According to the mathematic results, Table 2 highlights our algorithm to support enough QoS level at the side of the licensed user while providing services to a license-exempt user.

Table 2. Power Control algorithm of the CR transmitter

Algorithm:

1. Initialize power of the CR to maximum
2. Calculate primary receiver's *SINR* Interference and channel capacity
3. **If** *SINR*<*SINRt*
Decrease P_c to approach desire SINR
Go to 2
Else
P_c set to P_{cmax} and calculate channel capacity
4. Change position of primary receiver
5. **End** loop
Return P_c, SINR, C

Table 3. The simulation parameters

P_c	Power of the CR transmitter	17dBm
P_{BS}	Power of the primary transmitter	30dBm
SINRt	Minimum required SINR	10dB
τ	Random variable of normal distribution	0 dB
α	Path loss exponent	2
L	Distance between primary and CR transmitters	1500m
B	Band width	1 Mhz
σ^2	Noise power	10^{-8}
R	Maximum primary network's radius	1000m
R0	Maximum CR network's radius	100m

5 Performance Evaluation

The formulas presented in the previous sections provide analytical outcome of the expected system. Some prominent parameter's values are mentioned in table 3. Considered that the system uses M-ary Quadrature Amplitude Modulation (MQAM) with 64-QAM. Analytical results in Figure 3 reveal that the *SINR* and the channel's capacity of primary receiver vary according to the different positions of the licensed user. Moreover, a minimum SINR value equal to 7dB occurs when the licensed user is at the closest to CR transmitter point ($\theta = \pi$). At the same time, ($\theta = \pi$), power of the cognitive transmitter at maximum level is 17dBm. Simultaneously, channel capacity is reduced to a minimum value. Results indicate that the harmful interference introduced to the receiver by the CR transmitter and that the *SINR* reaches a low level value (less than *SINRt*). According to *SINR* requirement on the path and the fixed distance between CR transmitter and primary base station, the power of the CR can be adjusted to achieve the desired level of *SINR*.

It is clear that, due to required *SINR* at the primary user, the power of the CR should be controlled to approach desired value. We above noted that the power algorithm increases the performance of the primary receiver by mitigating the harmful interference. Indeed, in the following figures we have illustrated the performance evaluation of our simulations. For this purpose, we used our custom simulator developed using the MATLAB programming language.

In Figure 3 variations of the primary receiver's *SINR* depicts that the minimum value of the *SINR* equals to 7dB and occurs at ($\theta = \pi$), at this situation power of the CR is 17dBm. Approximately variation of the *SINR* from farthest position to the closest place of the CR transmitter is 9dB.

The curve in Figure 4 reveals the capacity channel of the primary receiver varies from maximum 6 Mbps to minimum 2.5 Mbps at closest point to the CR transmitter with 17dBm power. The receiver's capacity channel altering is 3.5 Mbps, it shows the harmful interference affects primary receiver at $\theta = \pi$.

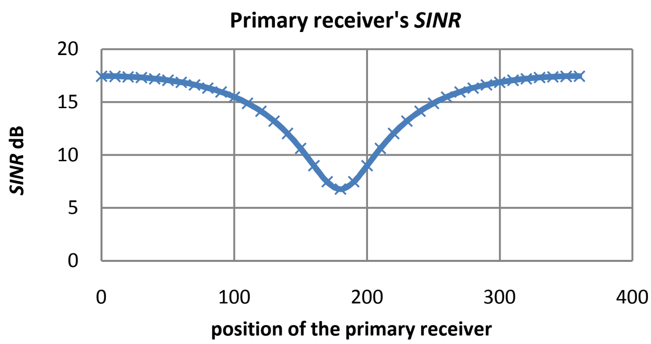

Fig. 3. Presence of CR transmitter and variation of the primary receiver's SINR (distance from primary transmitter is 1000m).

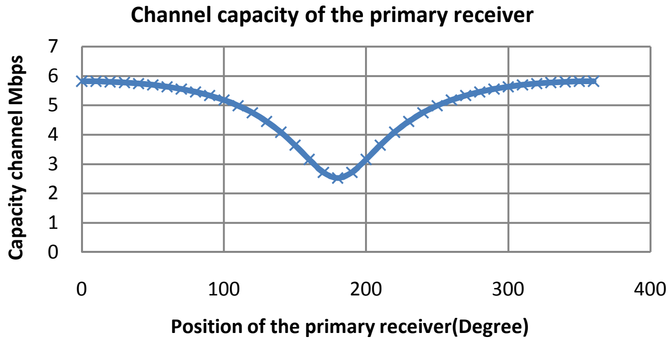

Fig. 4. CR transmitter existence and channel capacity variation at primary receiver**.**

In Figure 5 we depict the *SINR* of the primary receiver is reaching to the *SINRt* (10dB) due to adjusting power of the CR transmitter. As numerical results show the minimum power of the CR is 13dBm to approach minimum interference at $(\theta = \pi)$ (see Figure 7) meanwhile channel capacity of the receiver is 3.8 Mbps. It reveals the capacity optimizes amount 1.3 Mbps at that position (see Figure 6). As shown, in last three Figures (5, 6 and 7), while the primary receiver gets into the harmful interference area$5\pi/6 \leq \theta \leq 7\pi/6$, the power of the secondary transmitter should be adjusted.

6 Conclusions

In this work, we show that according to the location of a CR transmitter and its power, the performance of a primary user in terms of *SINR* and interference can be maximized. Although several methods have been used to mitigate interference we chose to implement a power control mechanism in this paper. The results show that to achieve minimum *SINR* namely 10dB at the primary user, the power of the CR transmitter should reach the value of 13dBm when the licensed user is at the closest to the CR transmitter position. Concurrently, the channel capacity reaches the value of 3.8 Mbps.

In future work, we plan to simulate several CRs that will share the common spectrum with a primary user and they will be laid in the critical common interference area. Then interference aggregated to a primary receiver will be mitigated towards the enhancement of the licensed CR user's QoS level.

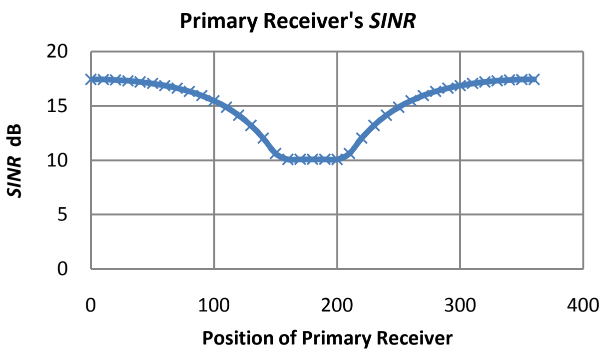

Fig. 5. Primary receiver's *SINR* adapt on minimum *SINR* according to get suit QoS level.

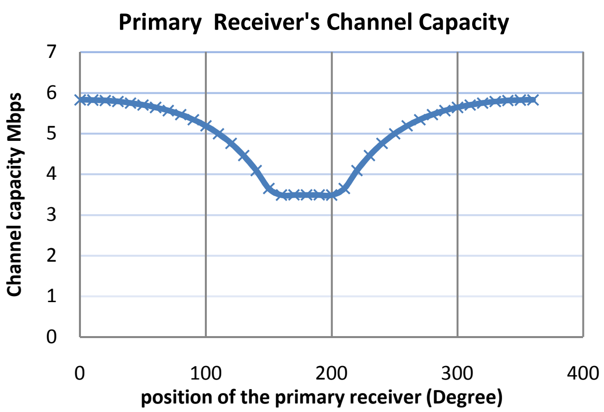

Fig. 6. Improving the QoS level of the primary receiver with respect to CR transmitter's power

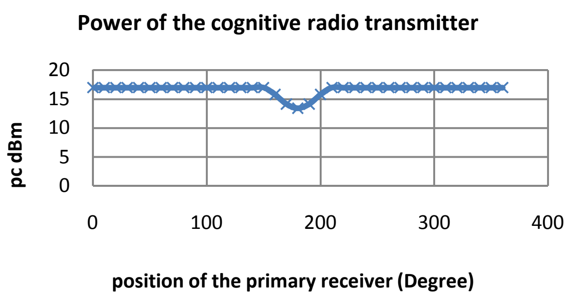

Fig. 7. CR transmitter's power and mitigate harmful interference to primary receiver.

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