Robust Transmit Power Control for Multiuser Cognitive Radio Systems using GA

Pooja Sharma, Pranshumaan, Shrishti Prasad and Janardan Sahay

Abstract: A cognitive radio (CR) network is a multiuser system. Cognitive users (CU) compete for limited resources in an opportunistic manner by interacting with each other for access to the available resources. In CR networks, proper power controlling is important to ensure efficient operation of both primary and cognitive users. In this paper, an algorithm is used to dynamically control transmission power, which is capable of achieving reasonably good solutions fast enough in order to guarantee an acceptable level of performance for CU without degrading the performance of primary user(s). Genetic Algorithm is used to enhance the convergence time.

Keywords: **Cognitive radio, Genetic Algorithm, Power allocation, Quality of Service.**

I. INTRODUCTION

The recent rapid growth of wireless communications has made the problem of spectrum utilization ever more critical. On one hand, the increasing diversity (voice, short message, Web and multimedia) and demand of high quality-of-service (QoS) applications have resulted in overcrowding of the allocated (officially sanctioned) spectrum bands, leading to significantly reduced levels of user satisfaction. The problem is particularly serious in communication intensive situations such as after a ball-game or in a massive emergency (e.g.,the9/11attacks).On the other hand, major licensed bands, such as those allocated for television broadcasting, amateur radio, and paging, have been found to be grossly underutilized, resulting in spectrum wastage. For example, recent studies by the Federal Communications Commission (FCC) show that the spectrum utilization in the 0–6GHz band varies from 15% to 85% [1]. This has prompted the FCC to propose the opening of licensed bands to unlicensed users and given birth to cognitive radio[2].

In this technology, cognitive(unlicensed)user(CU) is not assigned to any frequency band in advance, but are allowed to have opportunistic access to idle spectrums or to the busy ones without causing harmful interference to the primary(licensed)user(PU).

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The major advantage of cognitive radio technology is its ability to search available spectrums in its surrounding environment and adjust its transmit parameters accordingly to enhance the system performance. Hence, CU should be provided with the ability to perform radio scene analysis, channel state estimation and prediction, and transmit power allocation and dynamic spectrum management[3].

In wireless communications, transmission power is an important resource. Power control, also known as transmit power control, is a significant design problem in modern wireless networks. It comprises the techniques and algorithms used to manage and adjust the transmitted power of base stations and handsets. It also serves several purposes, including reducing co-channel interference (CCI), managing data quality, maximizing cell capacity, minimizing handset mean transmit power, etc.

There exist two important detrimental effects in wireless networks that decrease network performance. They are the time- varying nature of the channels and CCI. The average channel gain is primarily determined by large-scale path-loss factors such as propagation loss and shadowing. The instant channel gain is also affected by small-scale fading factors such as multipath fading. Because the available bandwidth is limited, the channels are reused for different transmissions. This channel reuse increases the network capacity per area, but, on the other hand, it causes CCI. Because of these effects, the signal-to-interference-noise ratio(SINR) at a receiver output can fluctuate of the order of tens of decibels. Power control is an effective resource-allocation method to combat these detrimental effects. The transmitted power is adjusted according to the channel condition so as to maintain the received signal quality. Power control is no longer one user's problem, because a user's transmit power causes other user's interferences.

The objective of power control in Cognitive networks is to control the transmit power to guarantee a certain link quality and to reduce CCI .To maintain the link quality, it is necessary to keep the SINR above a threshold that is called the minimum protection ratio. In power control, the transmitted power is constantly adjusted[4].

Related works can be found in [5–8].
In[5], the authors design a transmit power allocation system using fuzzy logic system is proposed to provide the CU with the ability to coexist with the PU in the same frequency band.

In [6], a power allocation approach is used in cognitive radio system based on the spectrum sensing side information in order to guarantee the protection of the PU.
Besides, a power allocation scheme based on ε-based greedy Monte Carlo method and a probability-based on utilizing the statistical information of PU's band occupancy with spectrum sensing errors are presented in[7] and [8], respectively.

These works have been extended to the scenario where multiple CUs exist, by considering the mutual interference between CUs and that caused by the PU, and hence the quality of service (QoS) requirement of CUs guaranteed in [9].

In this paper, we propose the use of GA in reaching a tradeoff between the maximum numbers of user having minimum SNR while guaranteeing the protection of PU in multiuser cognitive radio networks. In particular, we solve the power allocation problem of CUs by modeling a total-power-minimization optimization problem and using geometric programming (GP). A simple and fast distributed algorithm for power allocation is used, in which transmit powers of CUs are adaptively adjusted according to channel conditions, interference limit and target signal-to-interference-plus-noise ratio (SINR).
The rest of this paper is organized as follows. Section II summarizes the assumed multiuser cognitive radio system model. Section III explains power control algorithm used. Numerical results are presented and investigated in Section IV. Finally, Section V concludes the paper.

II. System Model

In this paper, we consider a cognitive wireless network with one primary user and K secondary users, as shown in Fig 1. The system is modeled as a collection of separate (K +1) transmit-receive pairs with a single channel. All secondary users and the primary user operate on the same frequency band. All CUs are allowed to transmit at the same time and share the same frequency band by adopting code division multiplexing access (CDMA).The transmission mode for each CU is half-duplex in order to avoid self-interference caused by one node simultaneously transmitting and receiving.

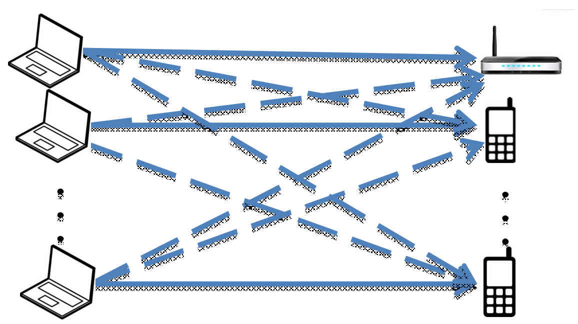

Figure 1: System model showing Primary transmitter and receiver and K Cognitive transmitter and receiver network

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$$r = \sum_{j=1,i\neq j}^{K} \sqrt{G_{ij}P_j}\, h_{ij} b_i \boldsymbol{s_j} + \sqrt{G_{ii}P_i} h_{ii} b_i \boldsymbol{s_i} + \sqrt{G_{i0}P_0} h_{i0} b_0 + \eta \quad (1)$$

Here r=received signal,
G_{ij}=channel gain between transmitter i and receiver j,
P_i= i th transmitter power,
b_i=transmitted bits,
h_{ij}=fading coefficients,
$\boldsymbol{s_i}$=spreading sequence for the ith CU's receiver,
G_{i0}=channel gain between PU's transmitter and CU i's receiver,
P_0=transmit power,
η=Gaussian noise.

The actual SINR at the output of CU i's receiver is

$$\Gamma_i = \frac{G_{ii}F_{ii}P_i}{1/\alpha \sum_{j=1,i\neq j}^{K} G_{ij}F_{ij}P_j + G_{i0}F_{i0}P_0 + \eta} \quad (2)$$

Where α is the spreading gain, $F_{ij} = |H_{ij}|^2$ where H_{ij}=matrix for fading coefficients which is assumed to be identically distributed Gaussian random variables with zero mean and constant variance.

GA is a biologically inspired heuristic search technique, belonging to the class of **Evolutionary Algorithm**s (EA).
It has been shown that a genetic algorithm based engine can provide awareness-processing, decision-making and learning elements of cognitive functionality.[10]They are well suited for optimization involving large search spaces.They can converge to adequate transmission parameter set according to a specified QoS. [11]Considering the non-uniform characteristic of the wireless spectrum with respect to noise, channel fading and attenuation, a local search needs to be conducted to determine optimum transmission power.
The algorithm can be understood by Fig 2.

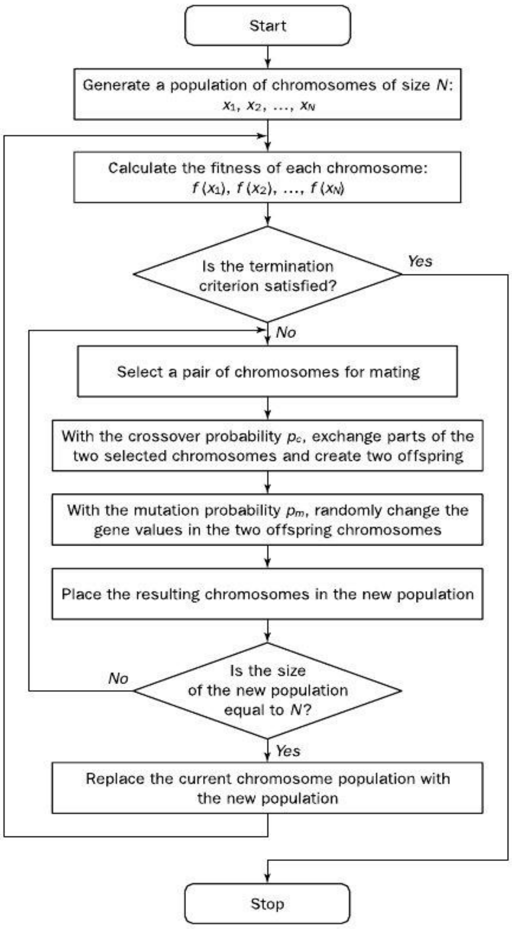

Figure 2: Flow Chart for GA[12]

III. Proposed Approach

In the proposed approach, the objective is to assign constrained transmit powers to all CUs, in order to minimize the total power consumptions while satisfying the target SINR constraint on CUs. Besides, we should also consider maintaining the interference introduced to the PU within a given interference limit, since CUs coexist with the PU in the same frequency band.

So, the inversion of equation (2) gives

$$\Gamma_i^{-1} = \frac{1}{\alpha}\sum_{j=1,i\neq j}^{K} G_{ii}^{-1}F_{ii}^{-1}G_{ij}F_{ij}P_i^{-1}P_j + G_{ii}^{-1}F_{ii}^{-1}G_{i0}F_{i0}P_i^{-1}P_0 + G_{ii}F_{ii}P_i^{-1}\eta \leq \gamma^{-1} \quad (3)$$

Where γ is the minimum required SINR.

Rearranging (3) gives

$$P_i - \sum_{j=1,i\neq j}^{K} \frac{\gamma G_{ii}F_{ij}}{\alpha G_{ii}F_{ii}} P_j \geq \frac{\gamma G_{i0}F_{i0}P_0 + \eta}{G_{ii}F_{ii}} \qquad (4)$$

Defining a matrix for above equation,

$$U = \left(\frac{\gamma(G_{10}F_{10}P_0+\eta)}{G_{11}F_{11}}, \frac{\gamma(G_{20}F_{20}P_0+\eta)}{G_{22}F_{22}}, \ldots, \frac{\gamma(G_{K0}F_{K0}P_0+\eta)}{G_{KK}F_{KK}}\right)^T \quad (5)$$

$$F_{i,j} = \begin{cases} \frac{\gamma G_{ii}F_{ij}}{\alpha G_{ii}F_{ii}}, & i \neq j, i,j = 1,2,\ldots,K \\ 0, & i = j \end{cases} \quad (6)$$

So, equation (4) can be rewritten as

$$(\mathbf{I_N} - \mathbf{F})\mathbf{P} = \mathbf{U} \qquad (7)$$

Where $\mathbf{I_N}$stands for *N X N*identity matrix.

The optimal transmit power can be obtained by the iteration of

$$\mathbf{P}(k+1) = \mathbf{FP}(k) + \mathbf{U} \qquad (8)$$

Or

$$P_i(k+1) = \min\left(P_i', \frac{\gamma}{\Gamma_i(k)} P_i(k)\right) \quad (9)$$

Where $P_i' = min\left(P_{max}, \frac{G_{0i}F_{0i}}{\sum_{i=1}^{K}(G_{0i}F_{0i})^2}\varepsilon\right)$ (10) denotes the maximum power available for the CUs after making sufficient power available to the PU.

Where ε=predefined interference constraint on PU.

Genetic algorithms are a particular class of evolutionary algorithms used in computing to find exact or approximate solution. Genetic algorithms are inspired by evolutionarybiology such as inheritance, mutation, selection, and crossover. In computations the abstract representations of candidate solutions are chromosomes and set of chromosomes formed as population. Traditionally thechromosomes are randomly generated as binary strings of 0s and 1s, but other encodings are also possible.

In each generation the fitness of individual (chromosome) in population is evaluated and multiple individuals arestochastically selected from the current population based ontheir fitness. The new population is formed using mutation, crossover and selection operators and fitness of the individual chromosome. The algorithm terminates as maximum number of generations are reached or satisfactory fitness level has been reached for the population [13]. For example, we can use simple genetic algorithm (SGA) provided in Goldberg [14] by forming the chromosome with the cluster of users, actions, and object functions to solve the current optimization problem. GA is used for optimizing equation (10). It helps in attaining the power available for CUs. GA is used to achieve better convergence rate.

IV. Simulation Results

The effectiveness of the model used is demonstrated by reduction of the total power consumption while satisfying QoS constraints of CUs and interference constraint on the PU, within minimum number of iterations. MATLAB simulations are used for the results.

Figure 2 shows the transmit power of each CU converges to steady state after 5 iterations for 4 users in which initial powers are set to be 10dB[9] without the application of GA for power optimization of equation(10).

Figure 3 and 4 show that the convergence performance has improved considerably on application of GA, such that the transmit power of each CU converges to steady state after 2 iterations for 4 users in which initial powers are set to be 1W and after 10 iterations for 5 users.

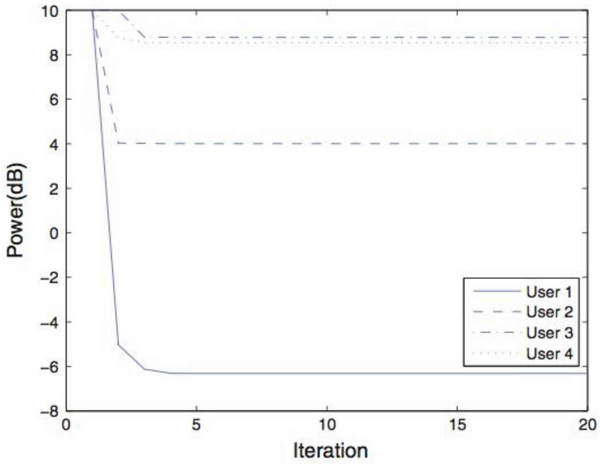

Figure 3: Transmit power for 4 CU's[9]

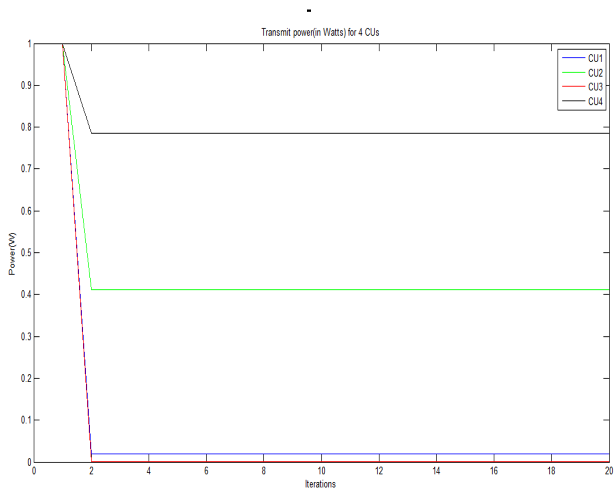

Figure 4: Transmit power for 4 CU's using GA

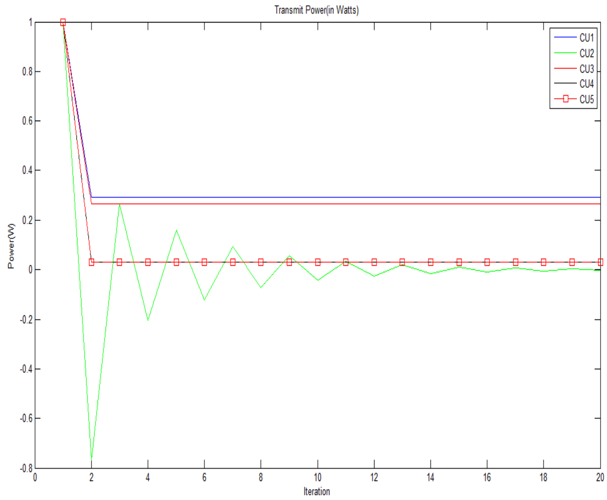

Figure 5: Transmit power for 5 CU's using GA

TABLE I

VALUES OF CONSTANTS USED

Symbol	Quantity	Values
N	Number of CU	5
α	Processing gain	16
$P_{i(min)}$	Minimum power	0 W
$P_{i(max)}$	Maximum power	1 W
-	Maximum no of iterations for GA	20
D	Distance matrix between cognitive transmitters and receivers	Input by User
ε		1 W
η	Noise	Randomly generated
γ	Minimum SINR	5 dB

ε has been described in text.

V. CONCLUSION

The scenario where multiple CUs share the same frequency band with one PU was analyzed.A power allocation scheme utilizing Genetic Algorithm was implemented that satisfied the targeted SINR requirements.Numerical and Graphical results were obtained to demonstrate that the proposed algorithm achieves significant improvements in Power efficiency.Comparisons were made with existing work on power allocation utilizing Geometric Programming[9], and GA was found to perform significantly better.
Further the work can be extended to the scenario of multiple Primary Users.

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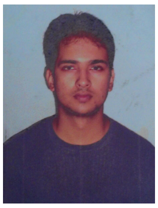

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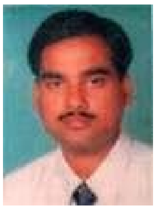

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